LA-UR-07-7475

Nuclear Data Experiments at LANSCE: Highlights 2007

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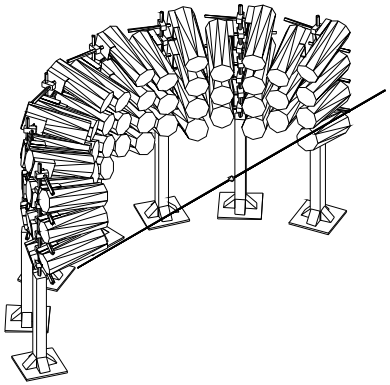
Los Alamos National Laboratory

Cross Section Evaluation Working Group Meeting
US Nuclear Data Program Meeting
Brookhaven National Laboratory
November 6-9, 2007

Nuclear data measurements at LANSCE are made with several instruments

GEANIE (n,xγ)

FIGARO (n,xn+γ)



DANCE (n,γ)

N,Z (n,charged particle)

Fission

LSDS

Double Frisch-grid fission chamber; also standard fission ion chamber; new detector station for fission and (n,alpha)

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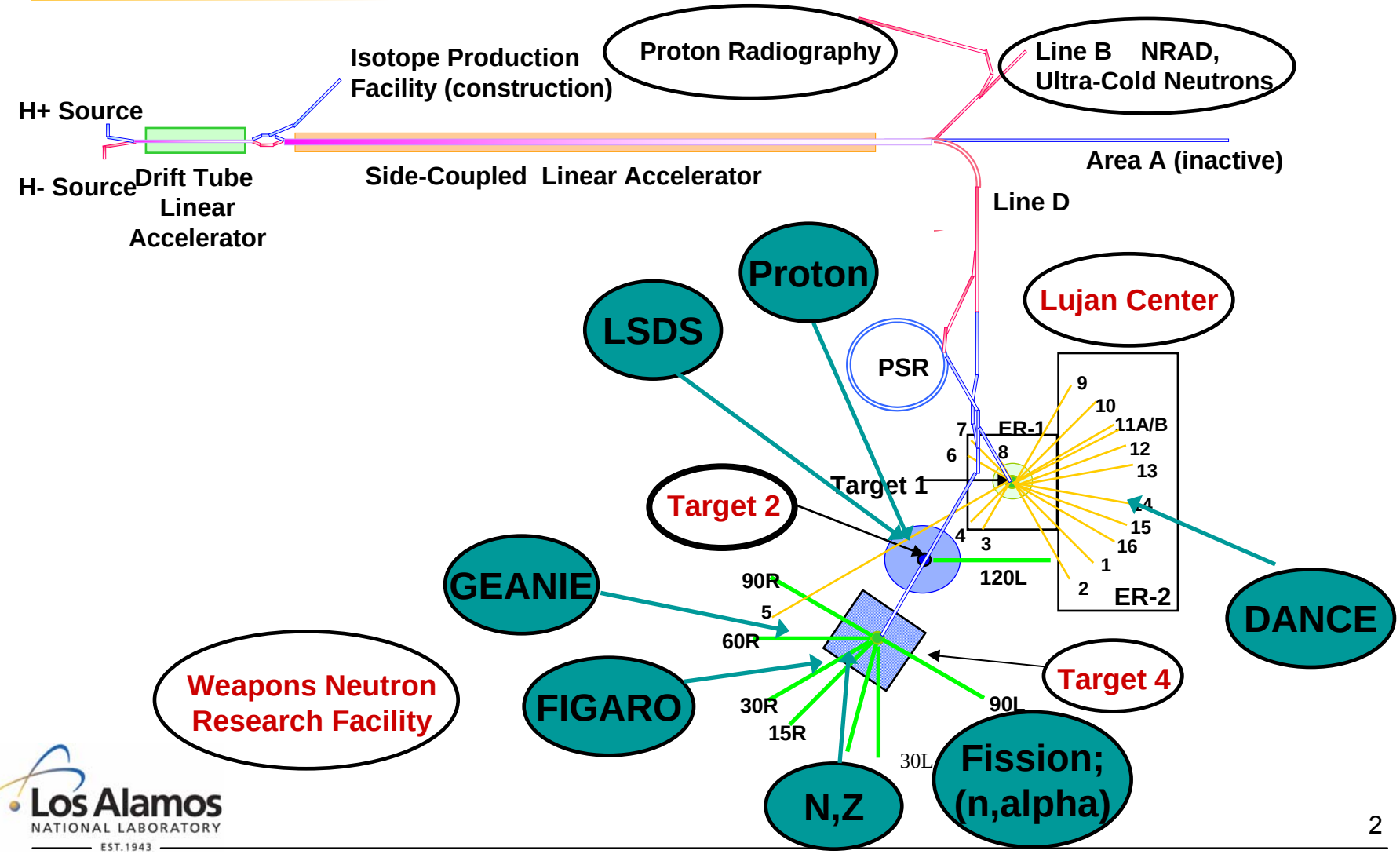
Nuclear data experiments at LANSCE use neutrons at the Lujan Center, Target 2 and Target 4



GEANIE (n,xγ)

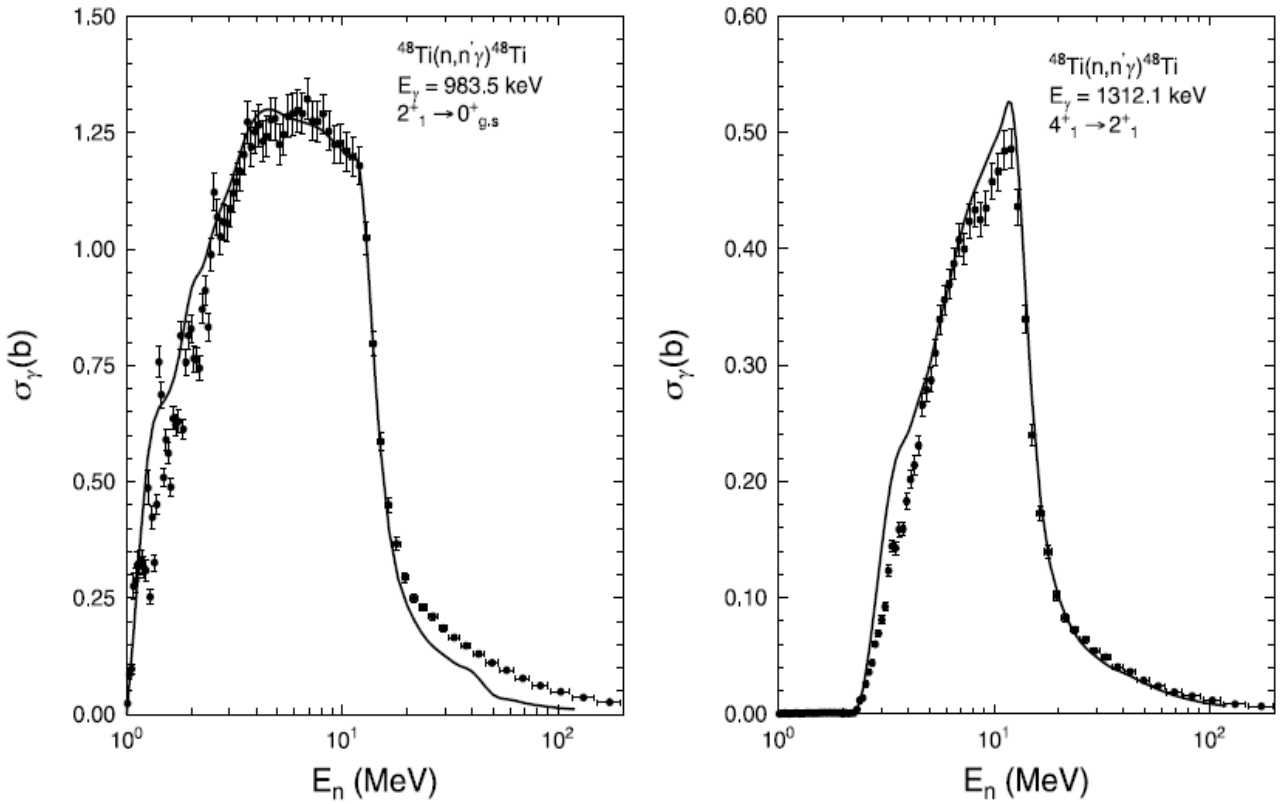
Recent Neutron-Induced Gamma-Ray Measurements with GEANIE at LANSCE/WNR

$$\sim 1\ \text{MeV} < E_n < 200\ \text{MeV}$$

- ^{203,205}Tl(n,2nγ) – N. Fotiades, levels, isomer lifetimes - Phys. Rev. C **76**, 0143092 (2007) and submitted to Phys. Rev. C.
- ^{48}Ti(n,xγ) – D. Dashdorj (NCSU/LLNL), preequilibrium angular momentum - Phys. Rev. C **75**, 054612 (2007) and cross sections - Nucl. Sci. Eng. **157**, 65 (2007).
- ^{135}Xe – N. Fotiades, High-spin states, Phys. Rev. C **75**, 054322 (2007).
- ^{103}Rh, ^{169}Tm, ^{nat}Lu(n,xγ), – levels, isomers – under analysis.
- ^{150}Sm(n,n'γ) – pre-equilibrium analysis continuing.
- ^{186}W(n,xγ) – analysis in progress.
- ^{70,72,74}Ge, ^{100}Mo,^{124}Sn, ^{130}Te, ^{136}Xe, ^{138}Ba, ^{nat}Lu(n,xγ) data acquired.
- ^{nat}Cu, ^{nat}Pb, ^{nat}Te, and ^{76}Ge(n,xγ) for 0$\nu\beta\beta$ decay experiment backgrounds – analysis in progress

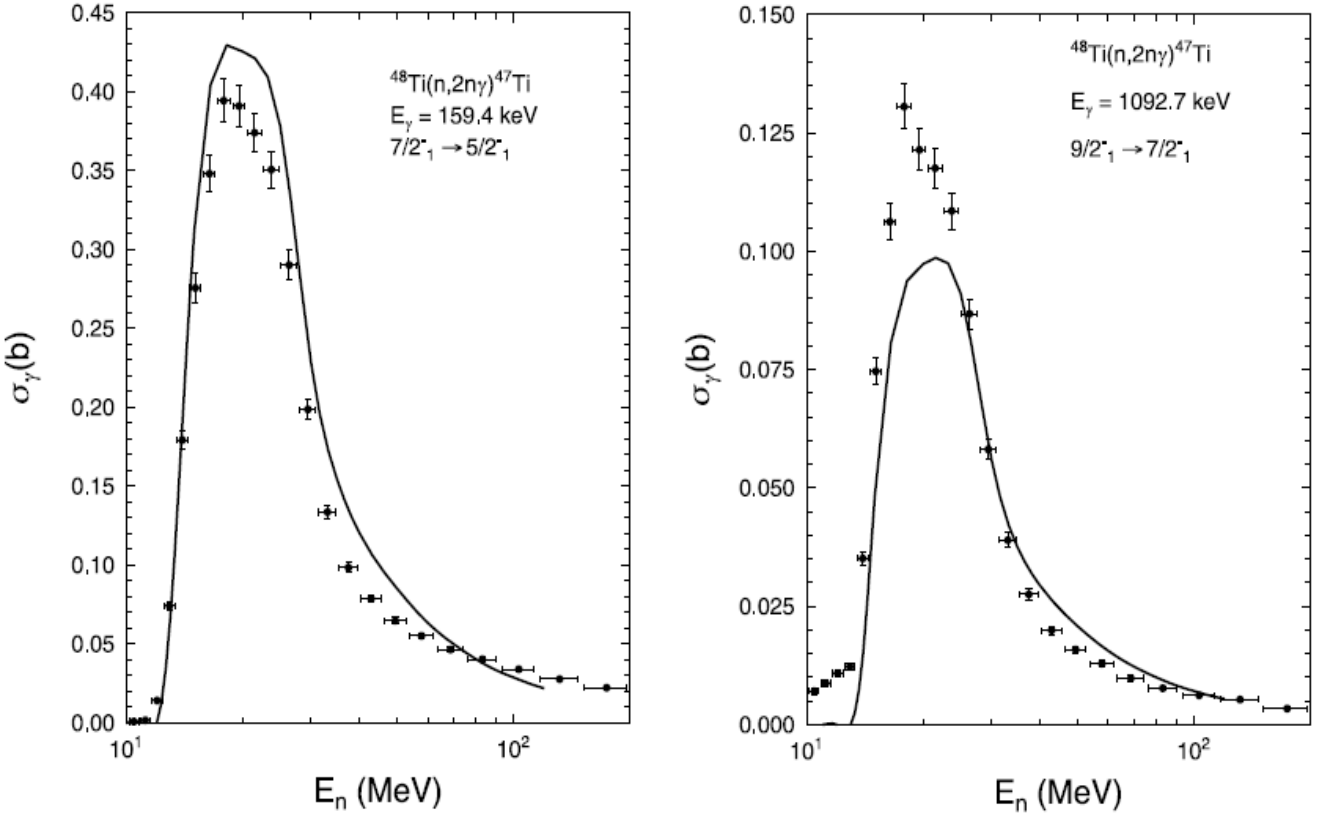
Contact:
Ron Nelson

Excitation functions of many gamma rays can be described by model calculations



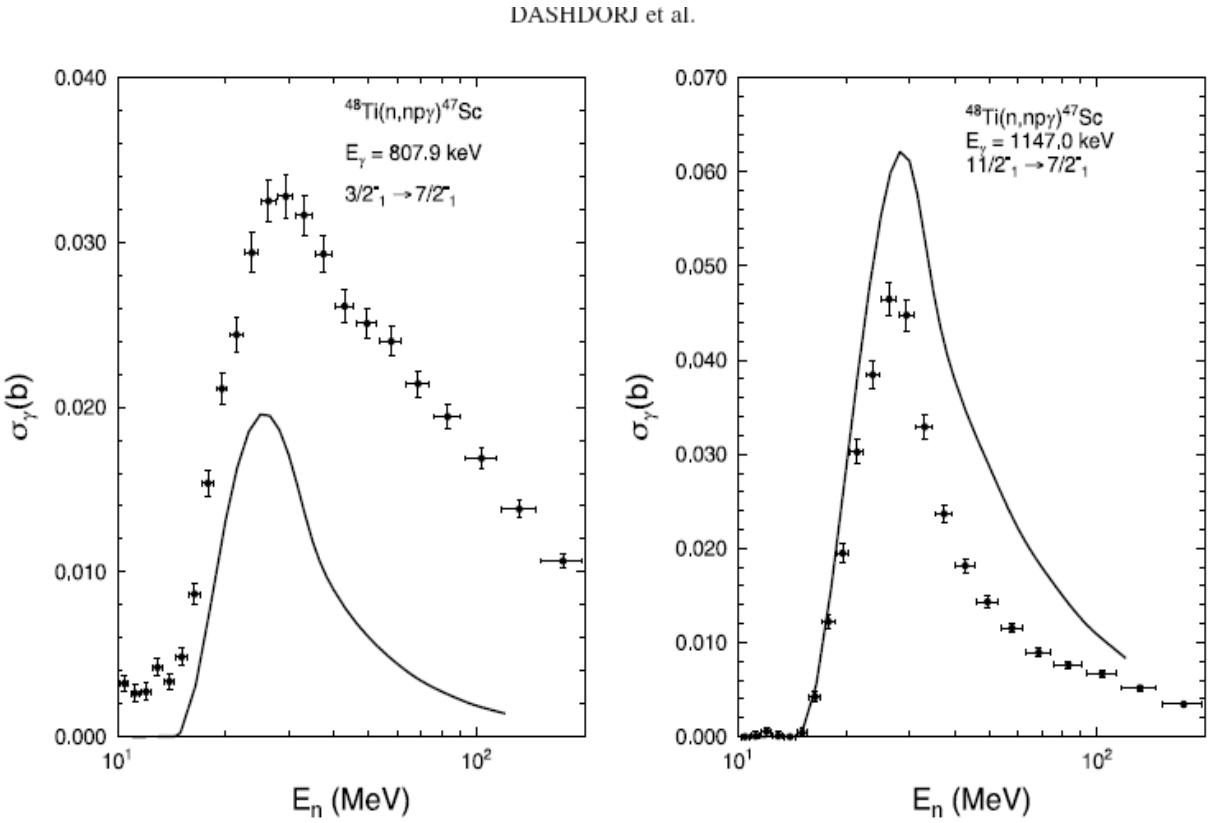
Ref.: D. Dashdorj et al.,Phys. Rev. C 75, 054612 (2007) and Nucl. Sci. Eng. 157, 65 (2007).

Branching ratios must be known correctly for calculations to match experiment



Ref.: D. Dashdorj et al.,Phys. Rev. C 75, 054612 (2007) and Nucl. Sci. Eng. 157, 65 (2007).

Some reactions are more difficult to fit with model calculations



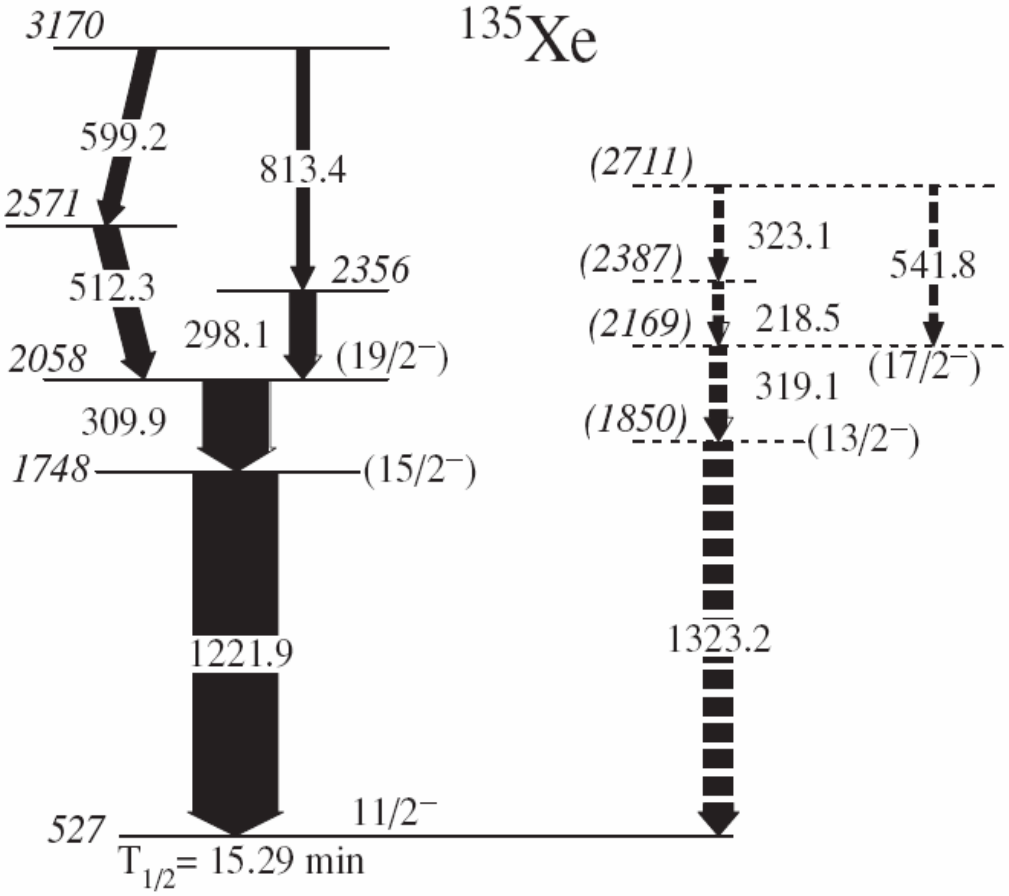
Ref.: D. Dashdorj et al.,Phys. Rev. C 75, 054612 (2007) and Nucl. Sci. Eng. 157, 65 (2007).

Nuclear spectroscopy can be investigated by a combination of charged-particle and neutron studies

"The high-spin structure of the ^{135}Xe isotope was studied via prompt -ray spectroscopy in two different experiments: (i) as a fission fragment following the fission of the ^{226}Th compound nucleus formed in a fusion-fission reaction and (ii) as an evaporation residue in the ^{136}Xe(n,2n)^{135}Xe reaction. The level scheme above the previously known 11/2$^-$ isomer …."

Ref.: N. Fotiades et al., Phys. Rev. C75, 054322 (2007)

Nuclear spectroscopy can be investigated by a combination of charged-particle and neutron studies



Ref.: N. Fotiades et al., Phys. Rev. C75, 054322 (2007)

Thallium isotopes have also been studied with GEANIE

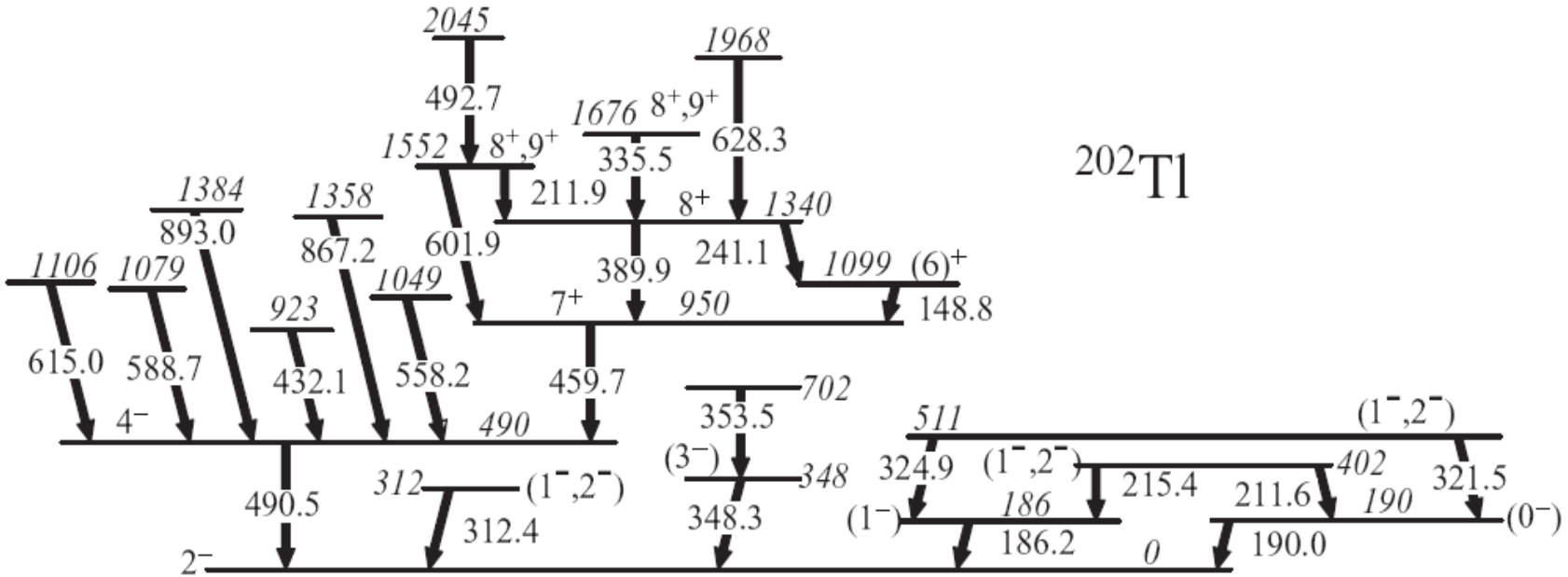
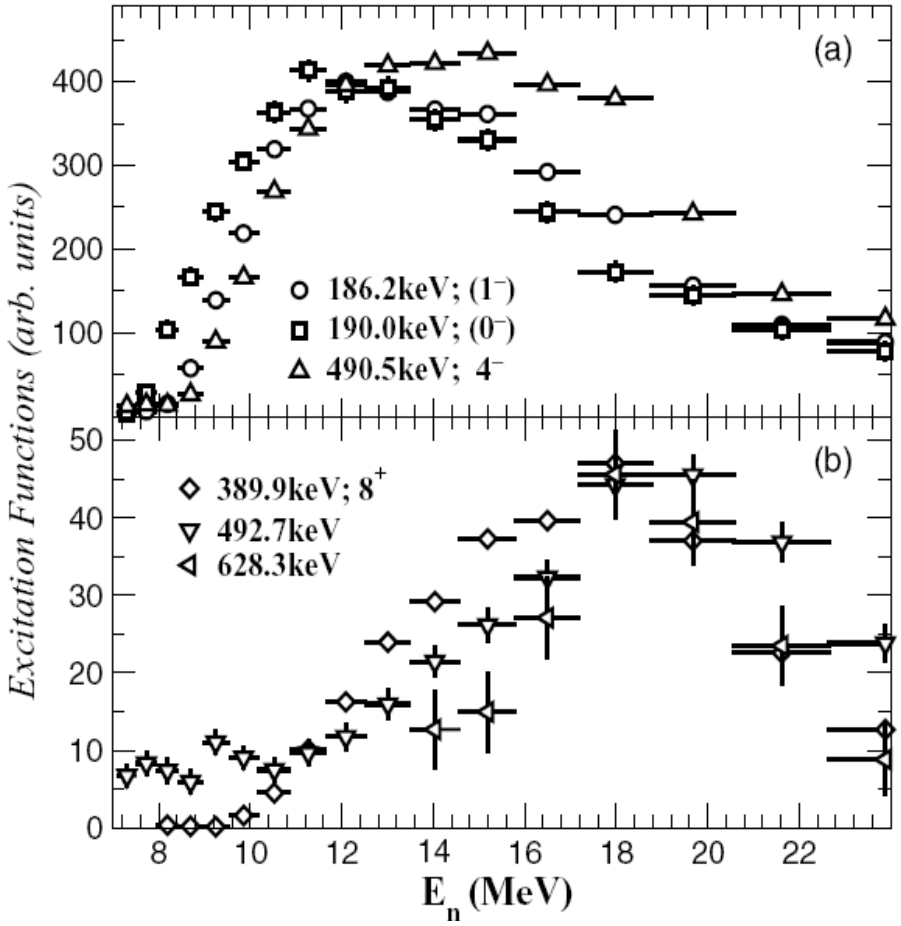


FIG. 2. Level scheme assigned to ^{202}Tl in the present work. Transition and excitation energies are given in keV.

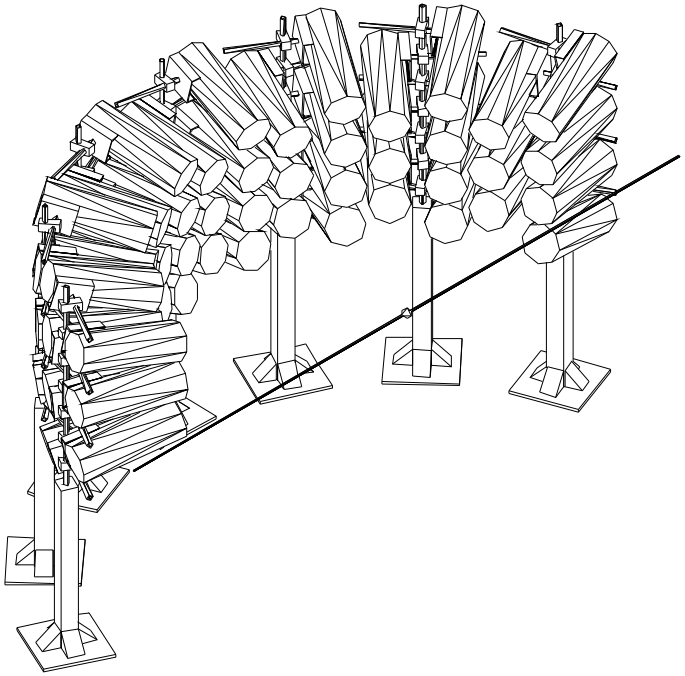
Ref.: N. Fotiades et al., Phys. Rev. C76, 014092 (2007)

Excitation functions limit spin-parity choices

^{202}Tl



FIGARO (n,xn+γ)



Present and future experiments at FIGARO/WNR: neutron-and-gamma emission spectra and ν-bar (fission)

1 MeV < E_n < 200 MeV

Fission

- ^{239}Pu(n,f): E_{fn}, E_{fgamma} ν-bar — In progress
- ^{235}U(n,f): E_{fgamma} — R. Nelson, in progress
- ^{237}Np(n,f): E_{fn}, ν-bar — ND2007 (CEA)

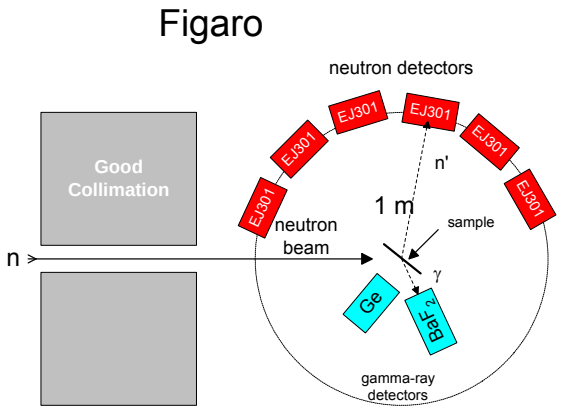
Non-fission [Gamma-ray trigger -- HPGe, BaF_2, NaI(Tl) and $LaCl_3$(Ce)]

- ^{56}Fe, $^{all\text{-}A}$Mo, others: E_n, — In progress

Contact: Bob Haight

FIGARO at WNR consists of an array of 20 neutron detectors and several gamma-ray detectors

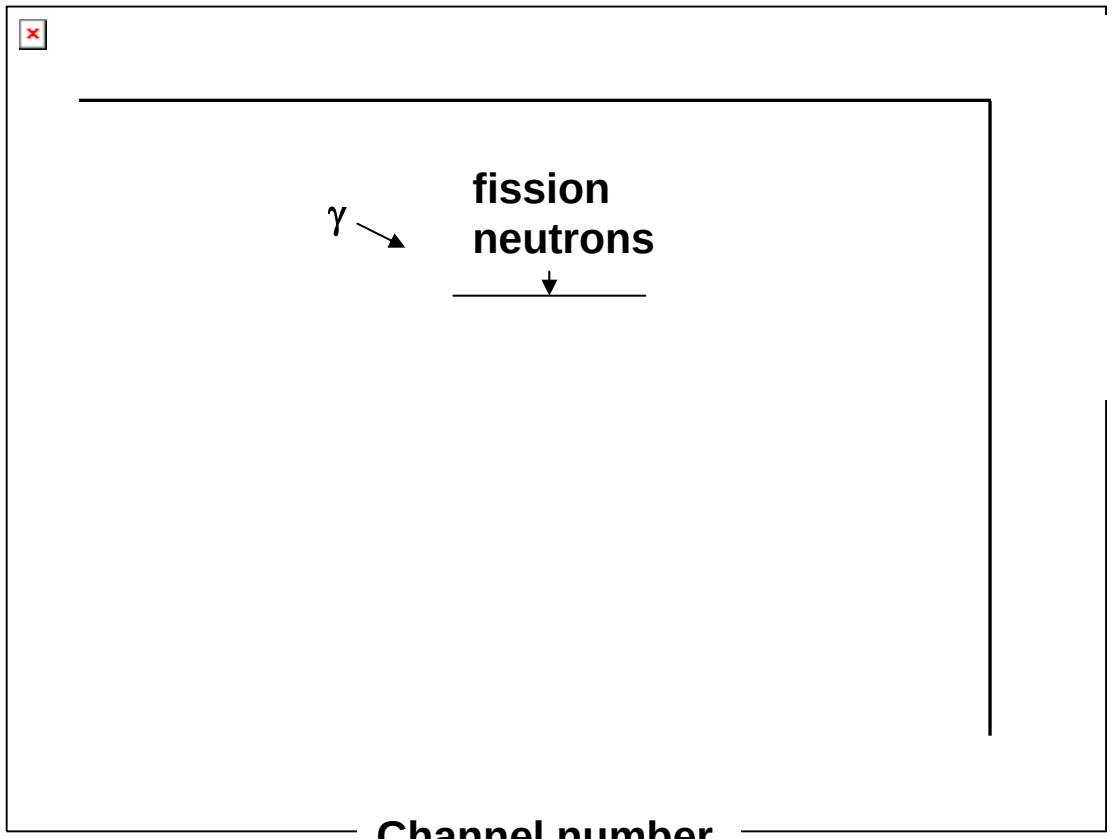
- Detectors
  - Fission ion chambers from CEA
  - 20 EJ301 liquid scintillation neutron detectors
  - BaF_2, BGO and $LaCl_3$ gamma-ray scintillators
- Double time of flight:
  - Source-fission chamber → Incident E_n
    -- Flight path = 22.7 meters
  - Fission chamber – neutron detector → E_{fn}
    -- Flight path ~ 1.0 meters
- Test of Los Alamos Model of fission
- In collaboration with CEA-Bruyères-le-Châtel (BRC, France)
- Completed: $^{235,238}U$, ^{237}Np neutron output
- In progress: ^{239}Pu neutron output and all gamma



FIGARO Schematic

FIGARO at WNR

Time difference spectrum from fission shows neutron spectrum

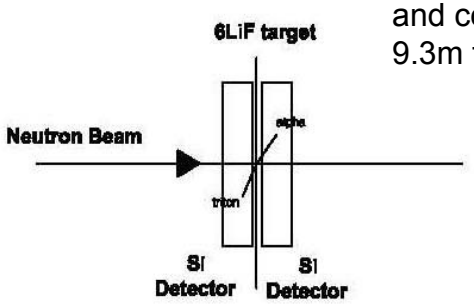


N,Z = (n,charged particle) cross sections

-- studied in two ways

^{6}Li(n,t)α reaction cross section measurement with Si detectors: goal is <5% uncertainty for 500 keV<E_n<10 MeV

The method:



Since $E_1 + E_2 = Q + E_n \rightarrow Q = E_1 + E_2 - E_n$

Events from ^{6}Li(n,t)α should have Q (4.78 MeV) > 0 and constant with E_n Using WNR flight path 90L, at 9.3m to extend the measurement below 100keV

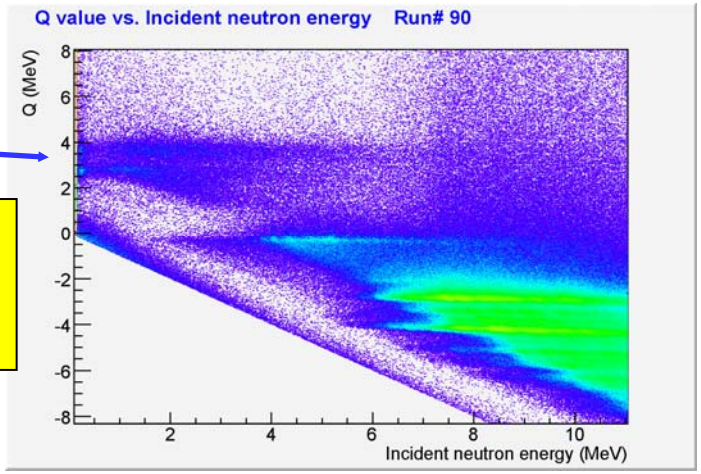
Data was taken in late 2006 on 90L, once the new building was ready.

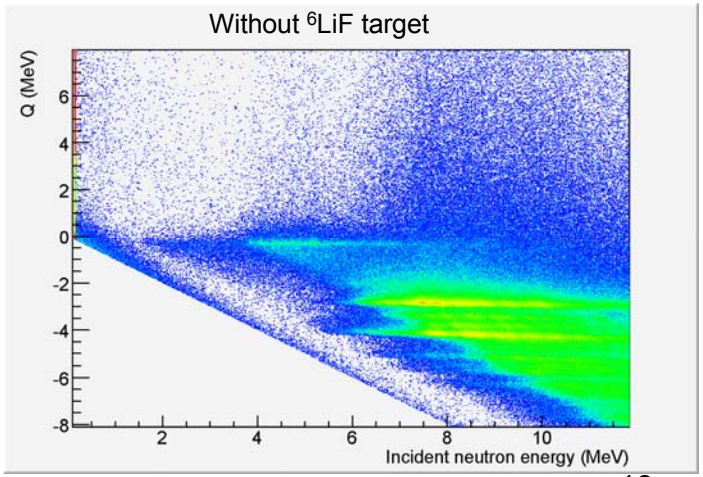
Only two months of data at a WNR rep rate of 40Hz.

Data analysis is in progress; results soon.

Target characterization still needed.

^{6}Li(n,t)α events





Contacts:
Matt Devlin
Terry Taddeucci

Angular distribution measurements at LANSCE/WNR: charged-particle detector array for (n,z) reaction studies

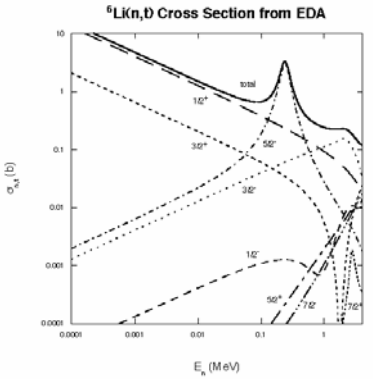
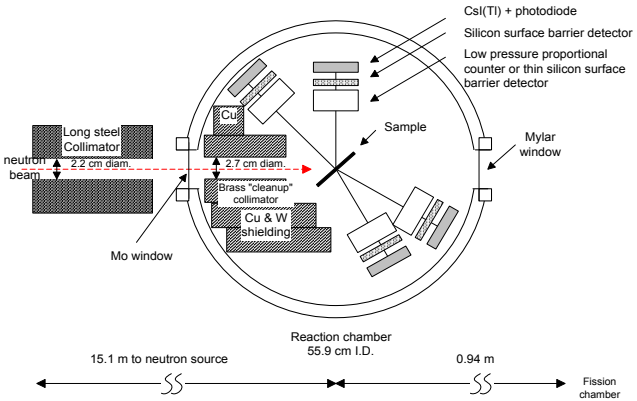


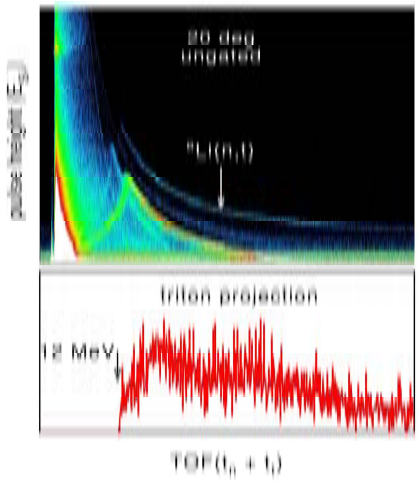
FIGURE 4. Partial-wave decomposition of the $^6Li(n,t)$ cross section from the EDA fit.

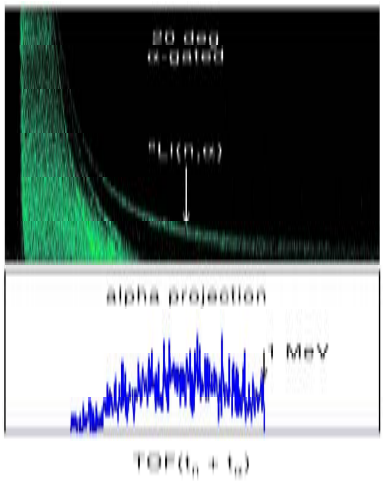
Angular distributions are needed to constrain the theoretical model for this reaction in the few MeV region.

Data were taken in 2006; angular distributions were given to Gerry Hale in Feb-Mar 2007.

Result to be published in Nuclear Data 2007 Proceedings

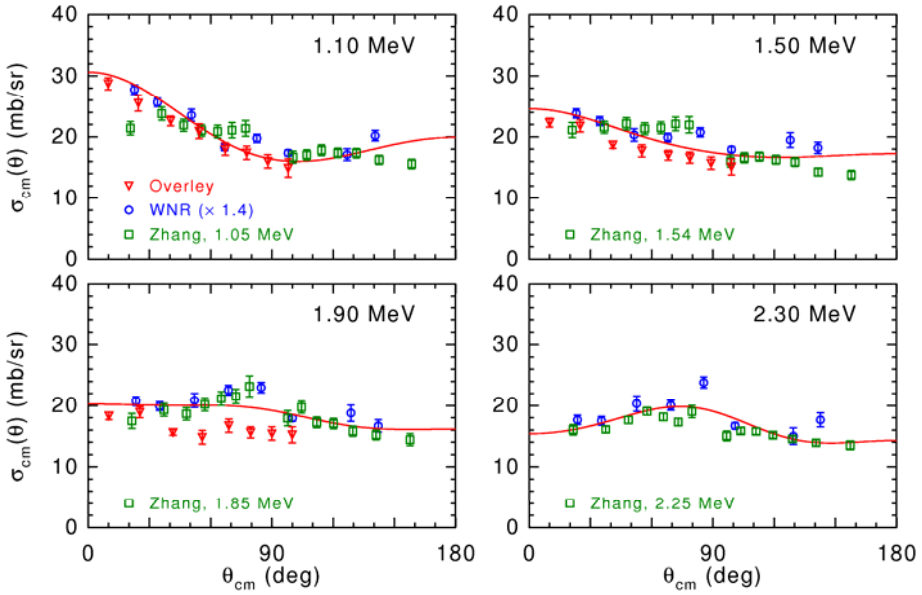


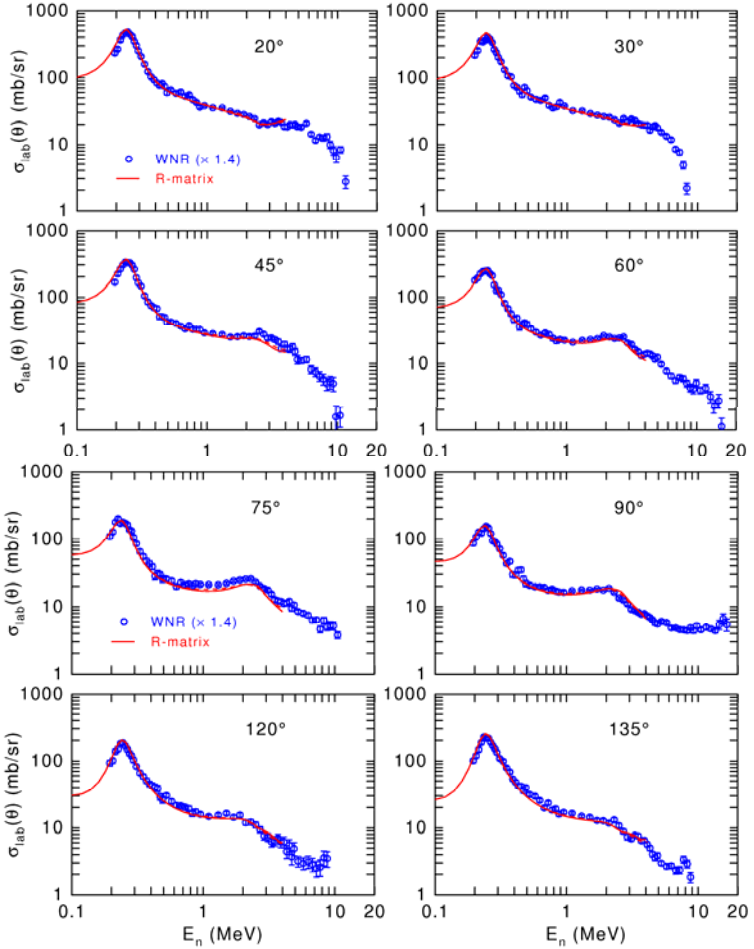




^{6}Li(n,t)α angular distribution measurements: results from 2006 data

- **Triton data from 2006 at eight laboratory angles: 20, 30, 45, 60, 75, 90, 120, and 135 degrees.**
- **Covers the incident neutron energy for tritons from 0.18 to >10 MeV; alpha particle data at 5 angles from 1.5 to 20 MeV**
- **More data taken recently**





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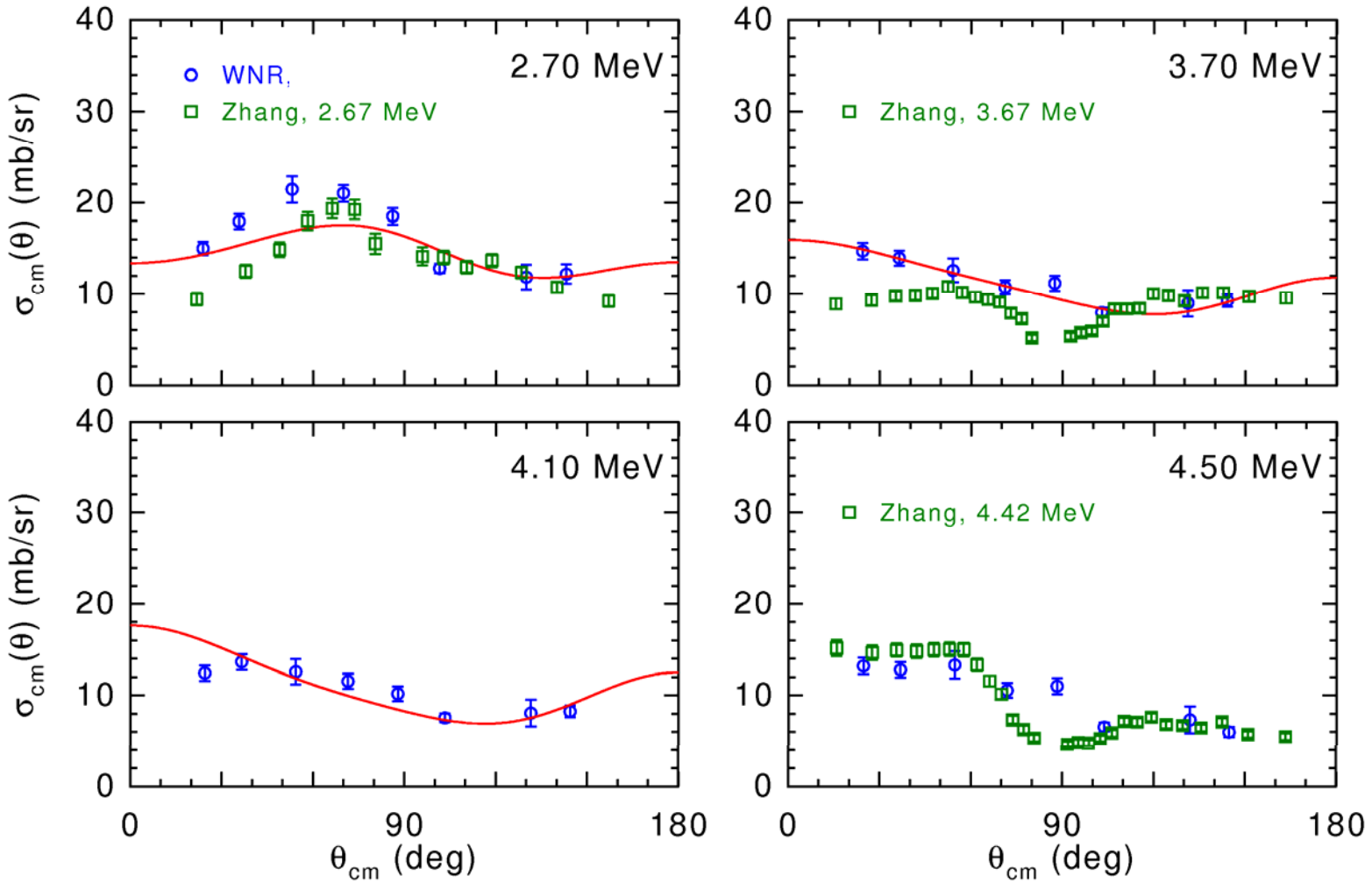
^{6}Li(n,t)α angular distribution measurements: more results



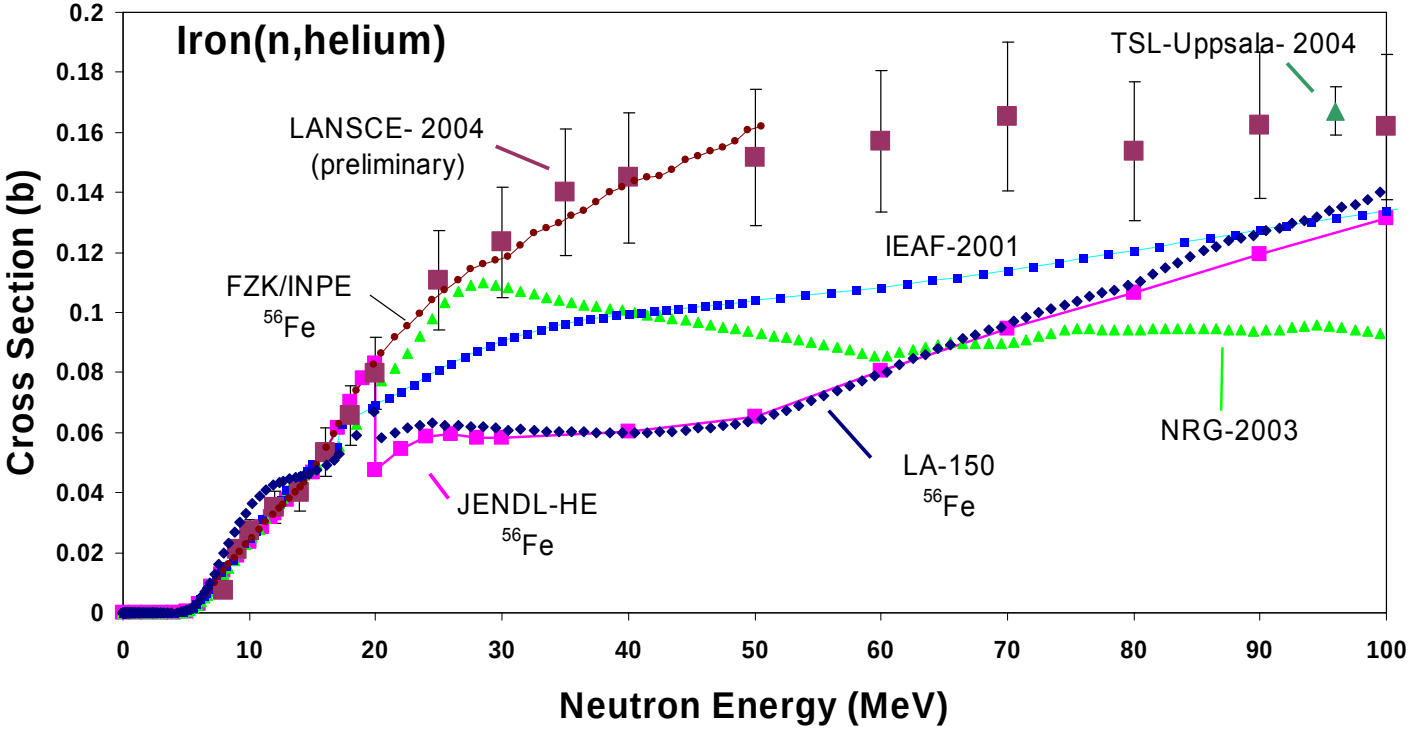
^{6}Li(n,t)α -- Current status, summary, and plans

- The ^{6}Li(n,t)α reaction cross section
  - data taken in 2006 with good statistics for E_n = 0.1 to 8 MeV; data analysis is in progress
  - need attention to systematic errors, target characterization, etc.
  - beamtime in Sep-Dec 2007 to address systematic errors, increase statistics (for E_n > 5 MeV)
  - want to measure the ^{6}Li(n,α)dn reaction channel as well
- Angular distributions
  - need to characterize the target foils
  - want more data to constrain the R-matrix fit in the 2-4 MeV range

We expect to be done taking data in December; analysis to be completed in early 2008.

We measure hydrogen and helium production cross sections for the Advanced Fuel Cycle Initiative

Previous data

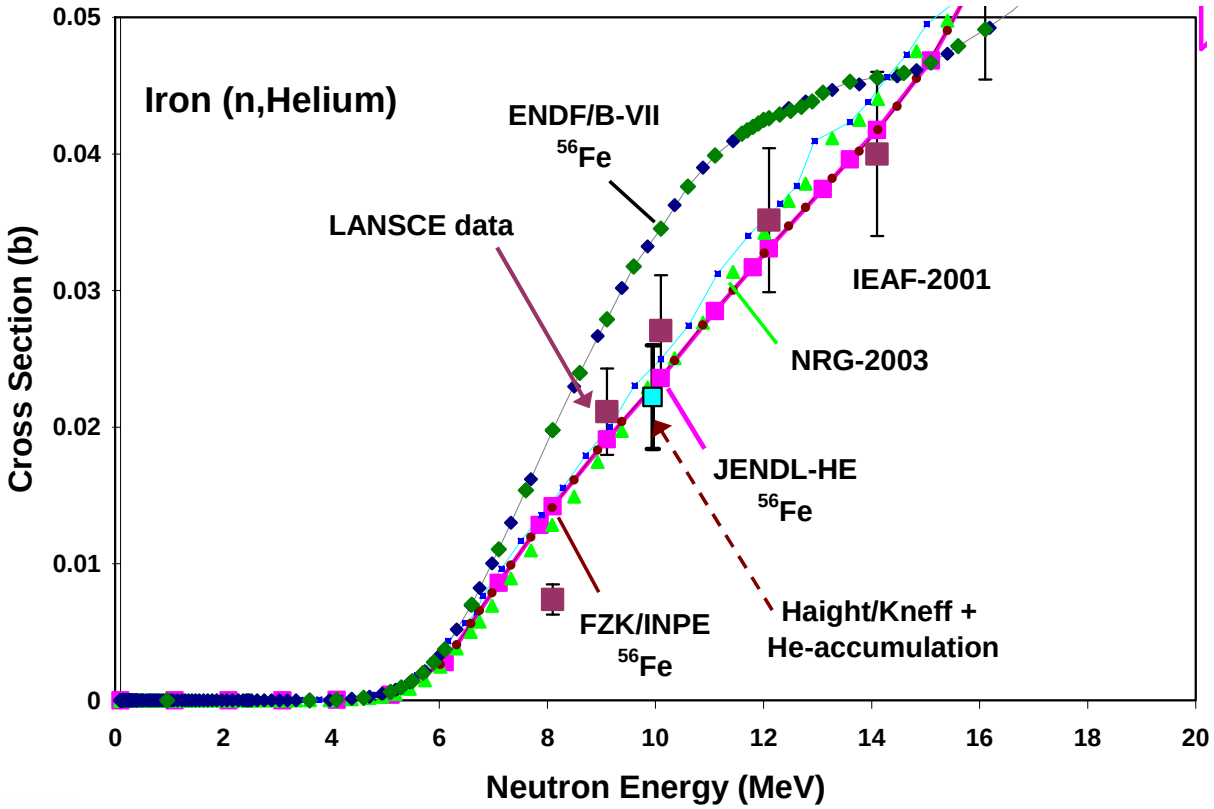


These data differentiate among evaluations

Contact:
Bob Haight

ENDF/B-VII has problems for helium production by neutrons on iron in the 7-13 MeV range

Previous data



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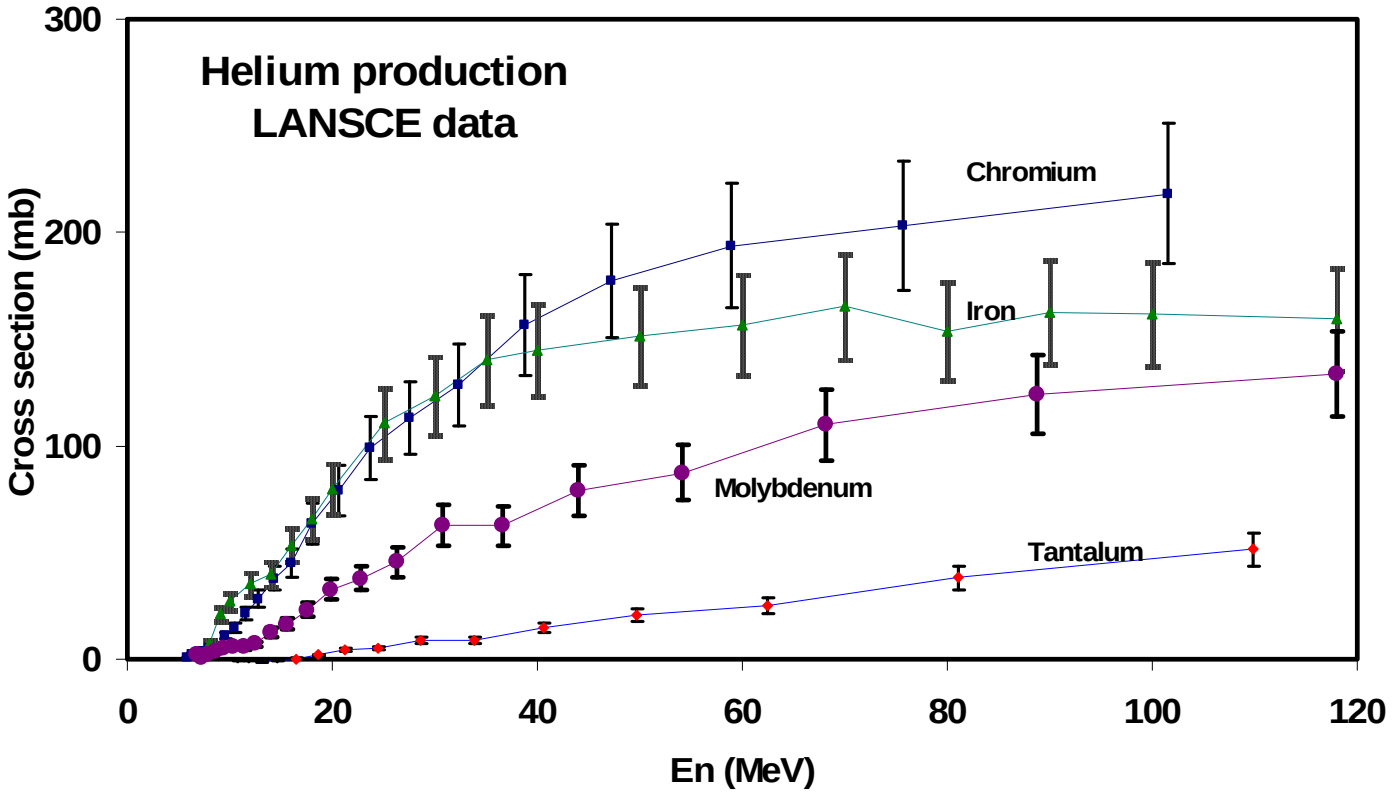
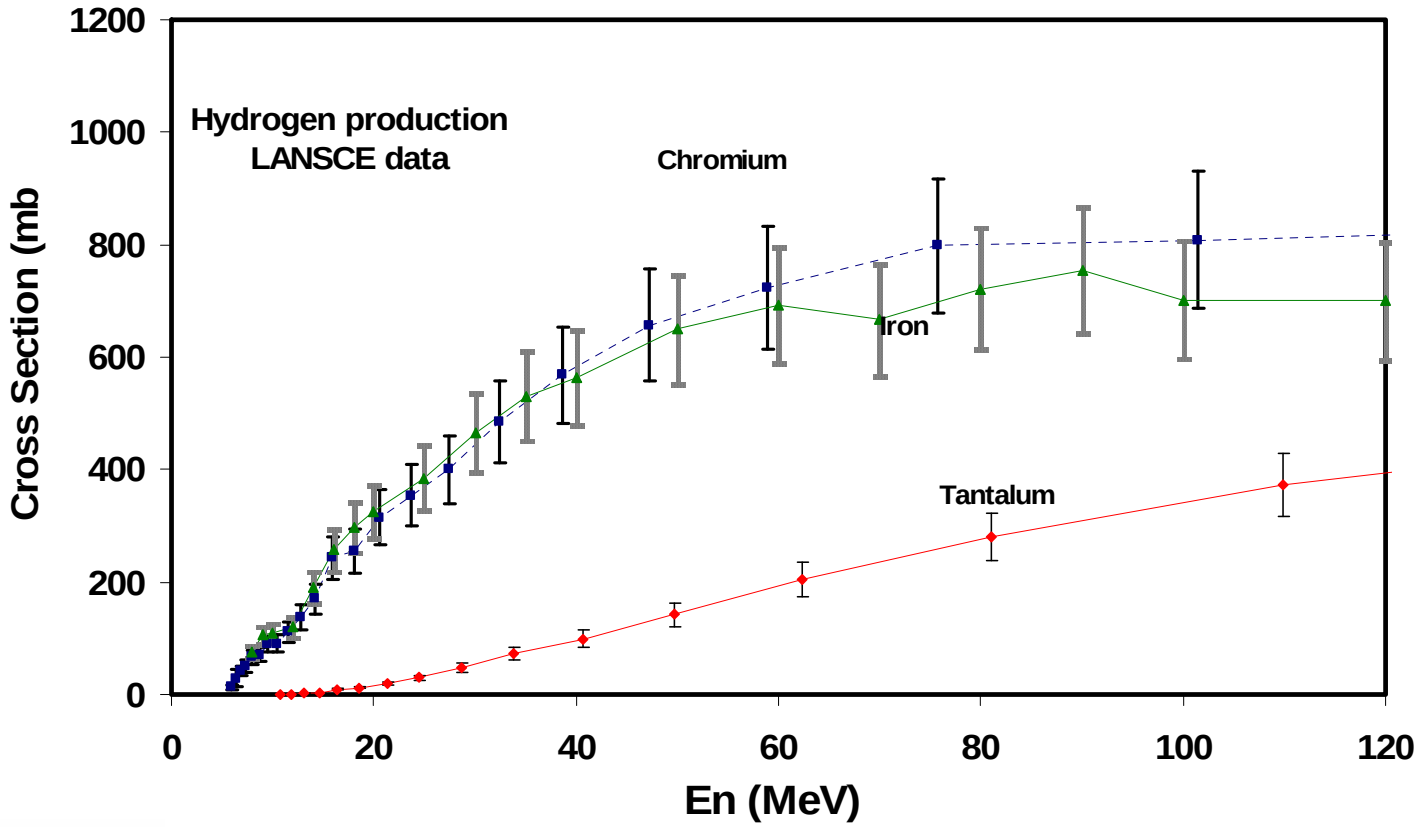
Helium production data is being measured for several materials for neutron energies up to 100 MeV

New data



Hydrogen production also is being measured

New data



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Plans for hydrogen and helium production cross sections for Global Nuclear Energy Partnership (GNEP)

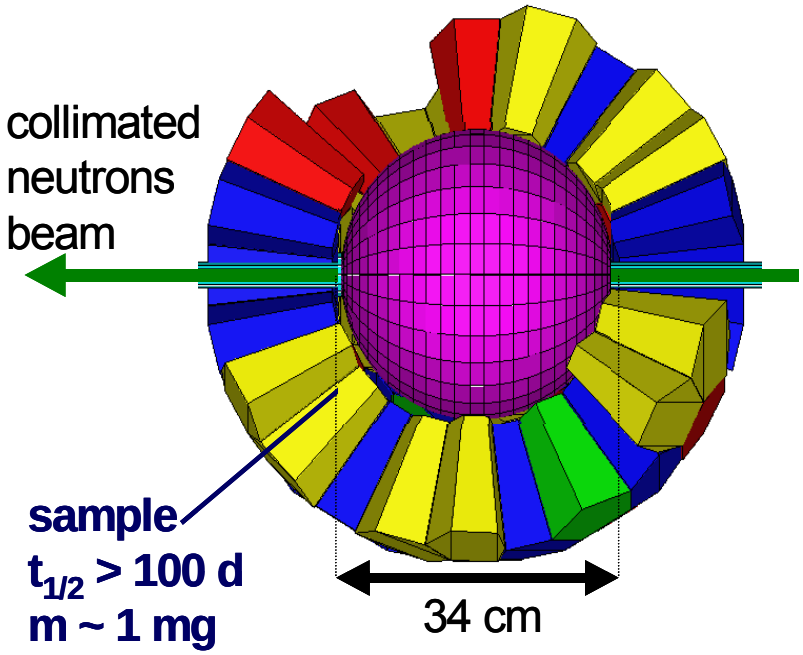
1 MeV < En < 100 MeV

- Mo(n,xp) and (n,xα) -- completed
- Zr(n,xp) and (n,xα) -- nearly completed
- "Minor" elements in alloys – planned for this year

Goal is to determine, e.g. helium production / dpa for GNEP application and for accelerated radiation damage testing with a spallation neutron source

DANCE (n,γ)

*D*etector for *A*dvanced *N*eutron *C*apture *E*xperiments - DANCE



neutrons:

- **spallation source**
- **thermal .. 500 keV**
- **20 m flight path**
- **3 10^5 n/s/cm^2/decade**

γ-Detector:

- **160 BaF_2 crystals**
- **4 different shapes**
- **R_i=17 cm, R_a=32 cm**
- **7 cm ^{6}LiH inside**
- **$\varepsilon_\gamma \approx$ 90 %**
- **$\varepsilon_{casc} \approx$ 98 %**

Contacts:
John Ullmann
Aaron Couture
Bob Rundberg

Analysis of DANCE Data is in Progress

^{94,95}Mo (S. Sheets, NC State Univ.)

^{143}Nd, ^{149}Sm (P. Koehler, ORNL)

^{152,154,157,160}Gd (W. Parker, Livermore)

^{151,153}Eu (U. Agvanluvsaan, Livermore)

^{151}Sm (R. Reifarth, Los Alamos and GSI)

^{203,205}Tl (A. Couture, Los Alamos)

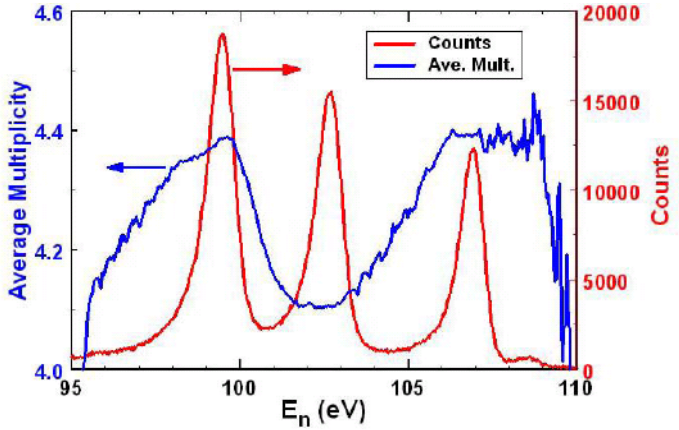
^{235}U PPAC (T. Bredeweg, M. Jandel, Los Alamos)

^{240,242}Pu (A Couture, Los Alamos)

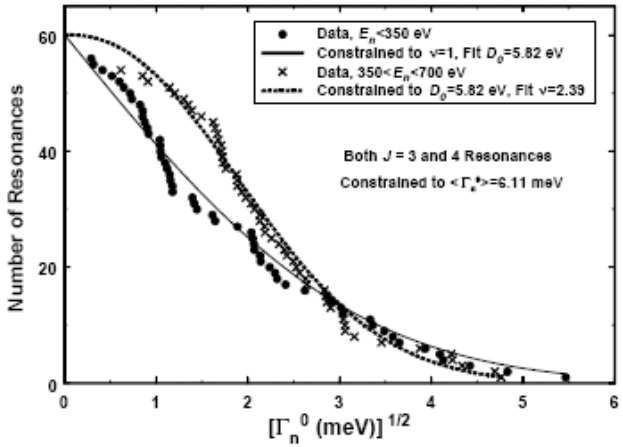
^{241,243}Am (T. Bredeweg, M. Jandel, Los Alamos)

^{242m}Am PPAC (C.Y. Wu, Livermore, M. Jandel, Los Alamos)

Spin Assignments for ^{147}Sm + n



<M> and Counts for several ^{147}Sm resonances



Spin assignments made for 140 resonances < 1 keV

- 34 firm J assignments for previously unassigned
- 8 firm assignments where only tentative assignments
- 14 resonances < 1 keV without firm J
  - (9 < 700 eV)
- 6 firm assignments disagree with Sukhoruchkin
- 6 previously firm resonances shown to be doublets

Actual assignments were made using combinations of various multiplicities rather than <M>

Non-statistical effects?

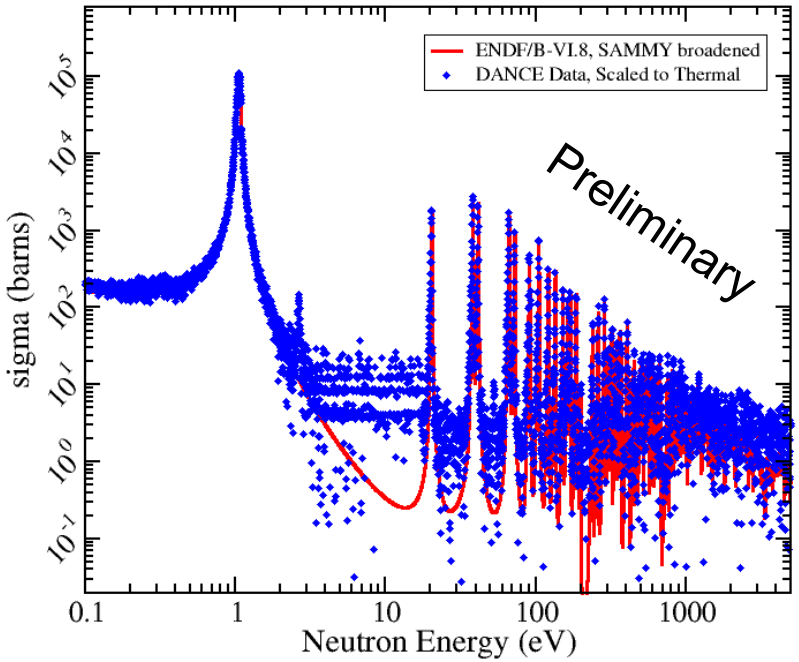
- ➢ Distribution of J=3,4 reduced neutron widths
  - Agree with each other
  - Disagree with Porter-Thomas

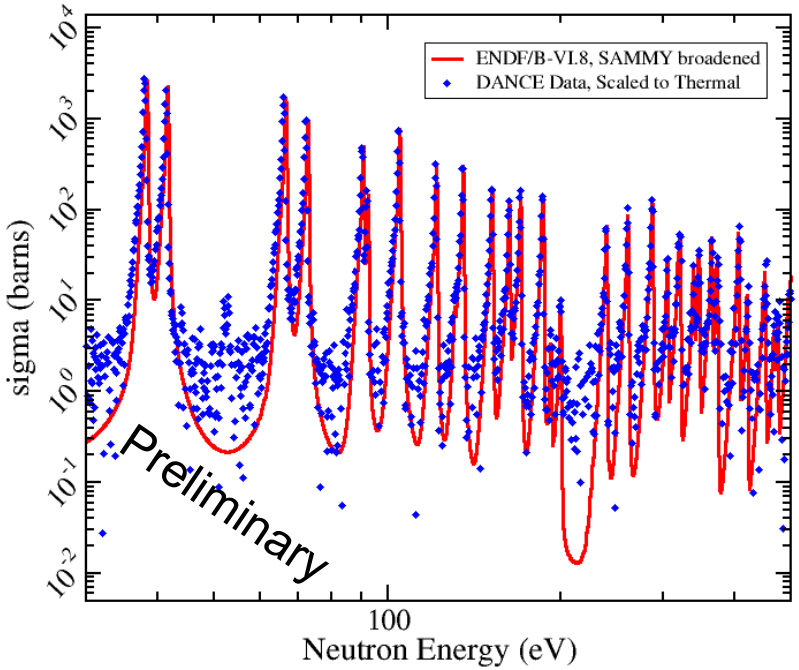
(Different conclusion from Gledenov and Koehler – incorrect spin assignments)

- ➢ Combined J=3,4 distribution
  - En < 350 eV follow Porter-Thomas (v=1)
  - 350 < En < 700 eV, not PT (v=2.39)
- ➢ Is result statistically significant?

Contact: Paul Koehler (ORNL)

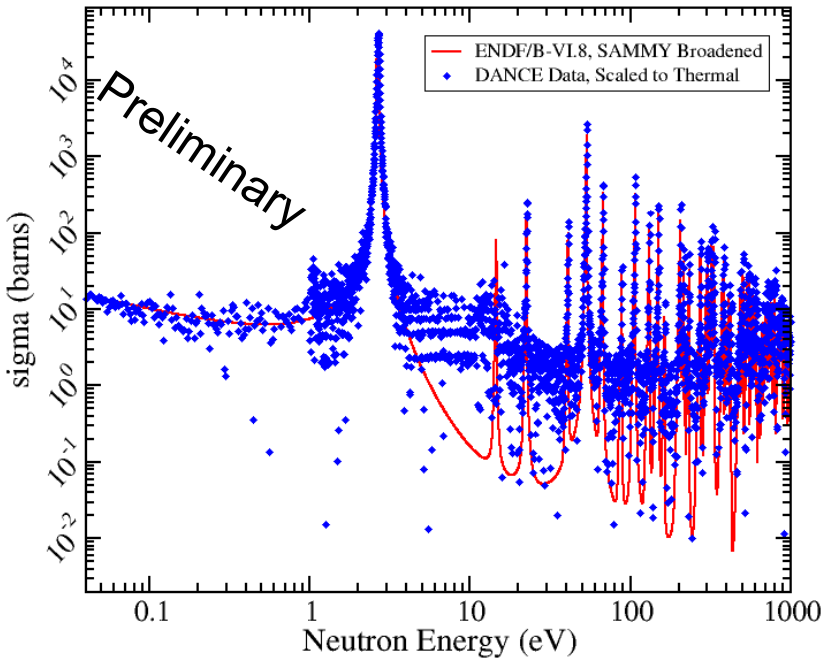
^{240}Pu Cross Section

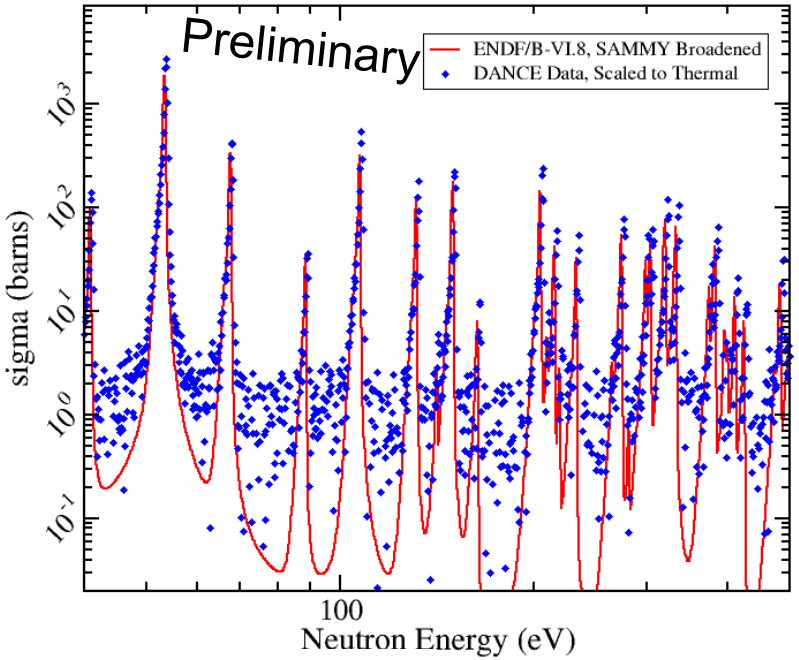


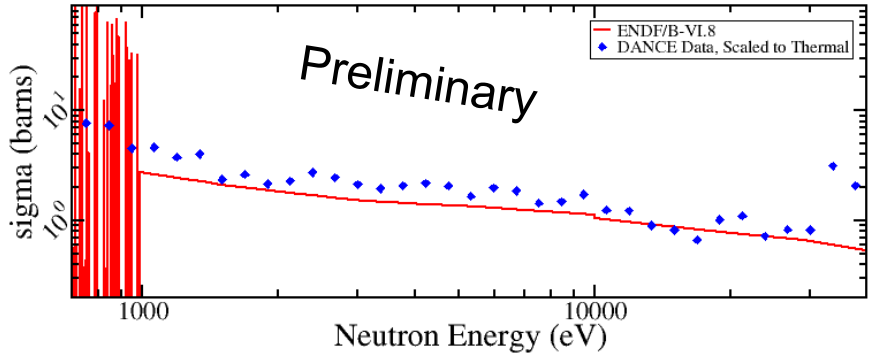


Contact:
Aaron Couture

^{242}Pu Cross-Section







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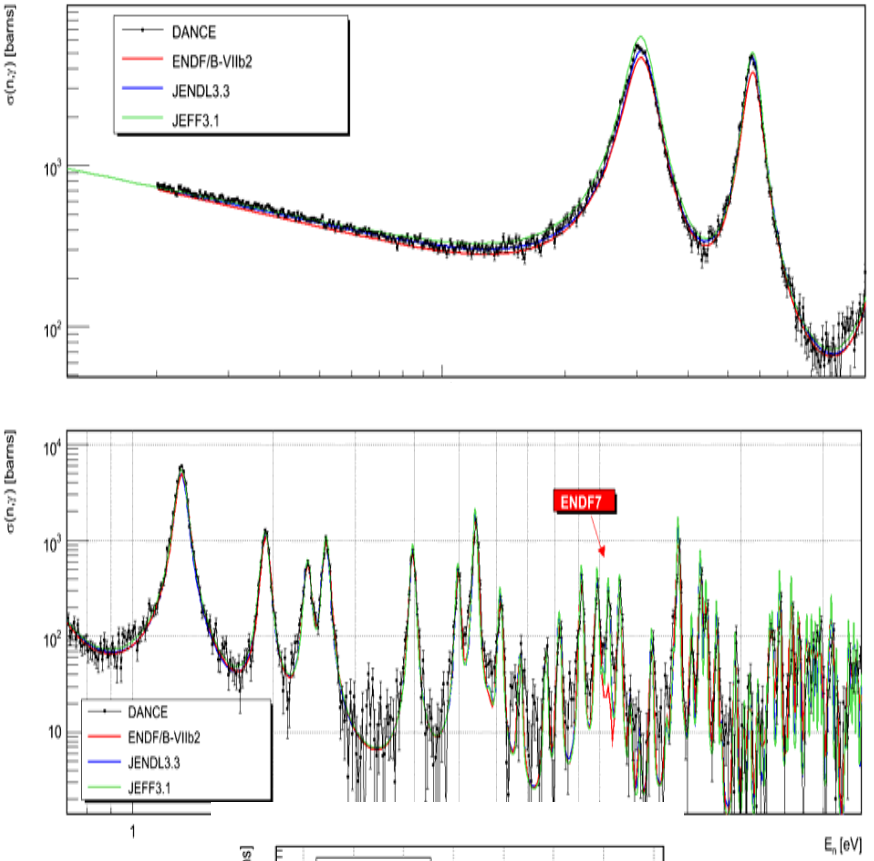
^{241}Am (n,γ) -- Cross section 0.02-36 eV

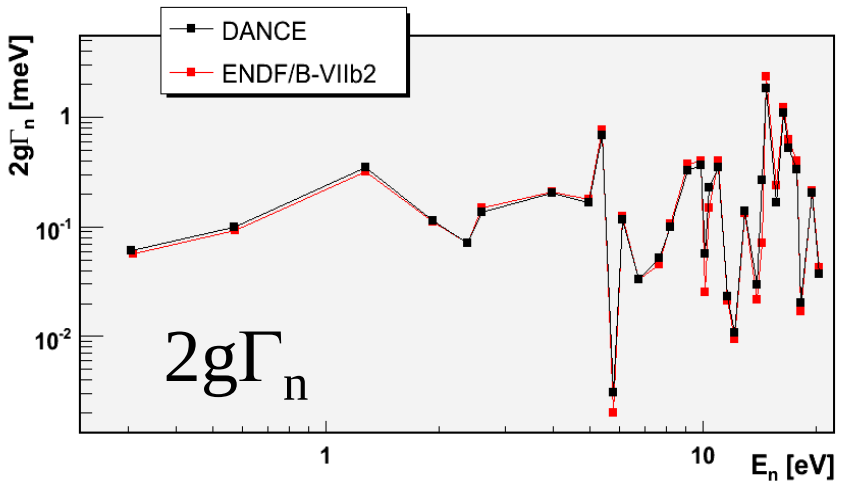
- At first two resonances our data are closer to JEFF and JENDL evaluations than ENDF
- self shielding correction was not applied yet on the data, and is planned at the last stage when precise SAMMY fit will be performed
- resonance at 10.4 eV is underestimated in ENDF evaluation (our analysis excludes fission contribution to a high degree)
- statistical uncertainties are decided mainly with dE/E choice
- at thermal (0.02-0.1eV) 4% systematic uncertainty should be considered, stemming from the inconsistency between our beam monitors

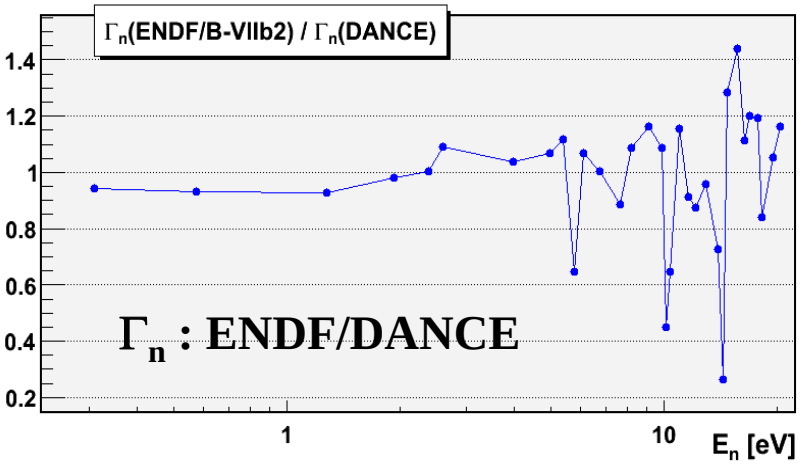


Contact:
Marian Jandel

^{241}Am Resonance Parameters

- **Comparison to ENDF/B-VII**
- **SAMMY7 was used to fit resonances below 20 eV**
- **Self shielding + multiple scattering effects included in the fitting procedure**
- **Neutron widths as a fitting parameter**
- **Gamma width kept from ENDF**
- **$2g\Gamma_n$ are compared in the upper panel**
- **lower panel shows the ratio of Γ_n : ENDF/DANCE**

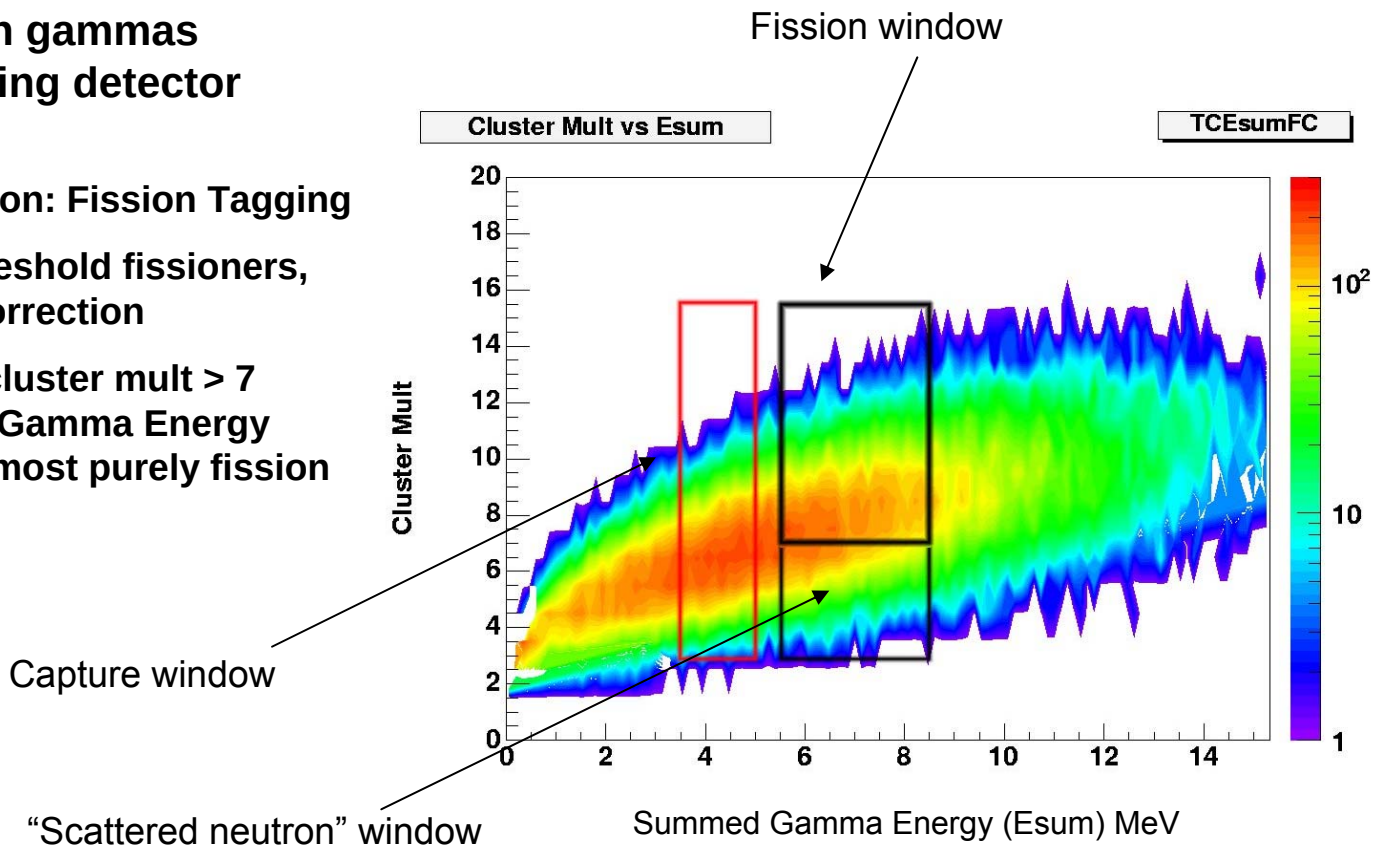




Capture/fission ratios are measured with DANCE

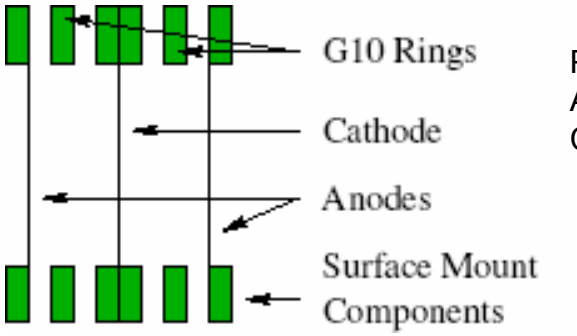
^{235}U fission gammas
Fission-tagging detector

- **Best Correction: Fission Tagging**
- **For many threshold fissioners, can make correction**
- **Events with cluster mult > 7 and Summed Gamma Energy >6 MeV are almost purely fission**

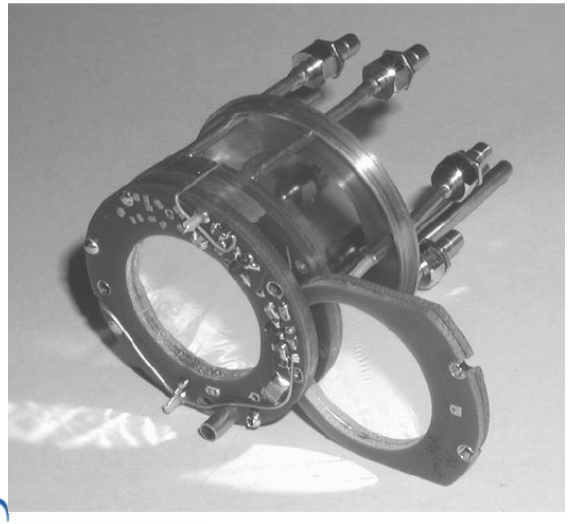


Background from fission gammas can be determined by normalizing ^{235}U spectrum

PPAC Detector for Capture and σ_γ/σ_f Measurements



Parallel-Plate Avalanche Counter



Close-up of PPAC showing removable cathode/target assembly

PPAC Assembly with gas lines and signal cables ready for insertion into DANCE center

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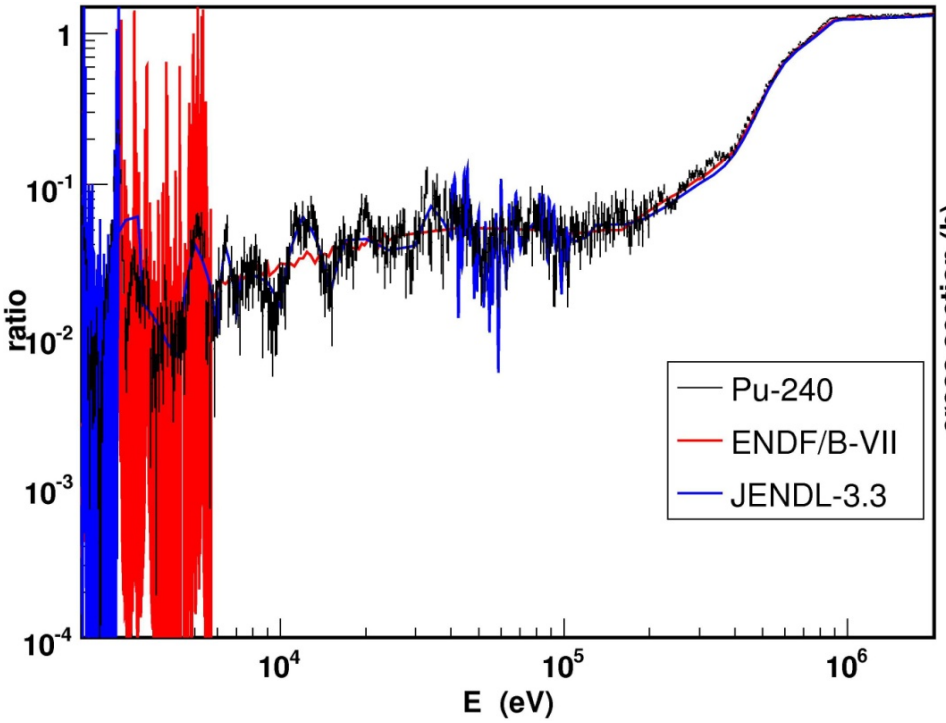
Fission Cross Sections

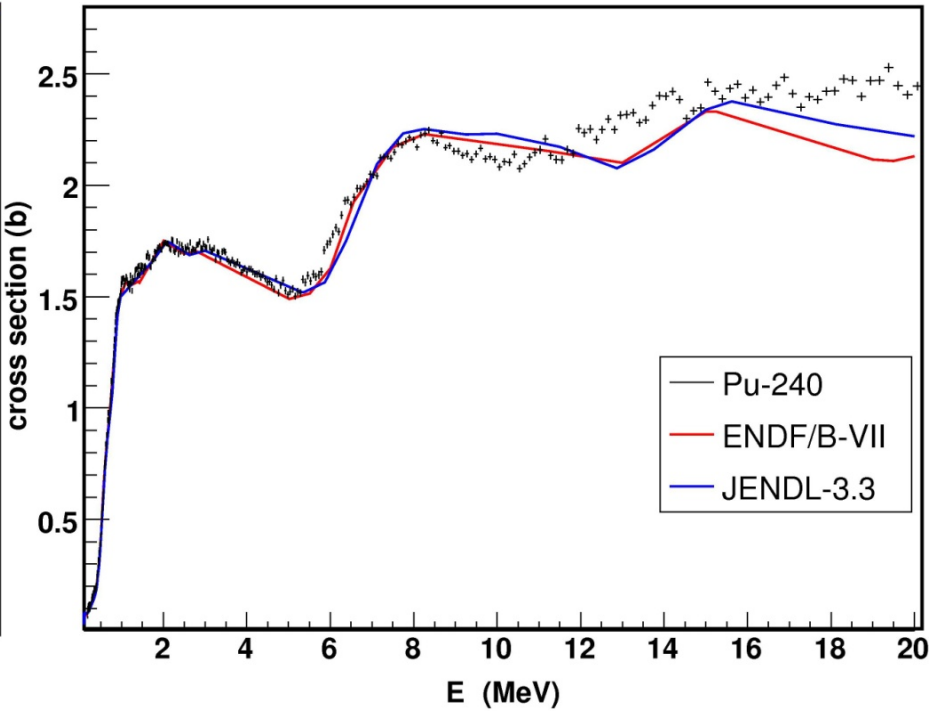
Recent and Future Fission Cross Section Measurements at LANSCE

- **Np-237** fission cross section from threshold to 200 MeV
  F. Tovesson, T. S. Hill, Phys. Rev. C 75, 034610 (2007).
- **Np-237** fission cross section from sub-thermal energies to 200 keV
  F. Tovesson, T. S. Hill, Nucl. Sci. Eng. (*in press*)
- **Pu-240 and Pu-242** from 1 keV to 200 MeV
  Measurements completed and results delivered to evaluators at the T-16 group at LANL.
- **Pu-239 and Pu-241**
  Preliminary results obtained, more data will be collected this year.
- **U-233**
  In progress, to be completed Sept. 2008

Contacts:
Tony Hill
Fredrik Tovesson

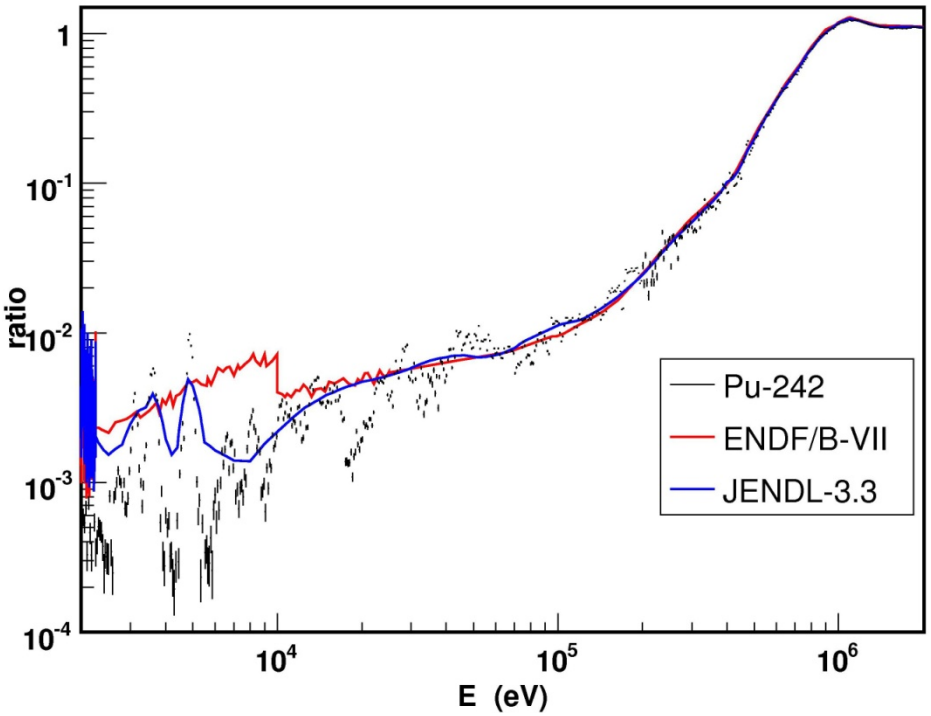
Pu-240 σ(n,f) results

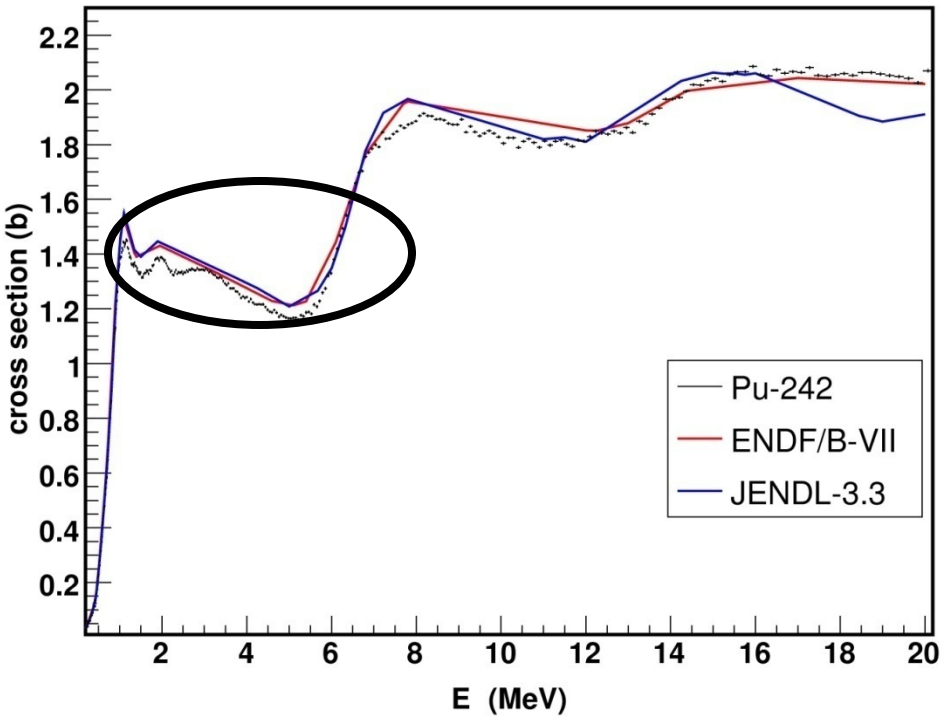




The evaluations agree well with the measurement in the unresolved resonance region and for first chance fission. At higher energies there are significant discrepancies.

Pu-242 σ(n,f) results





The JENDL evaluation is in good agreement with the data below reaction data. Both JENDL and ENDF seem to underestimate the first-chance fission cross section.

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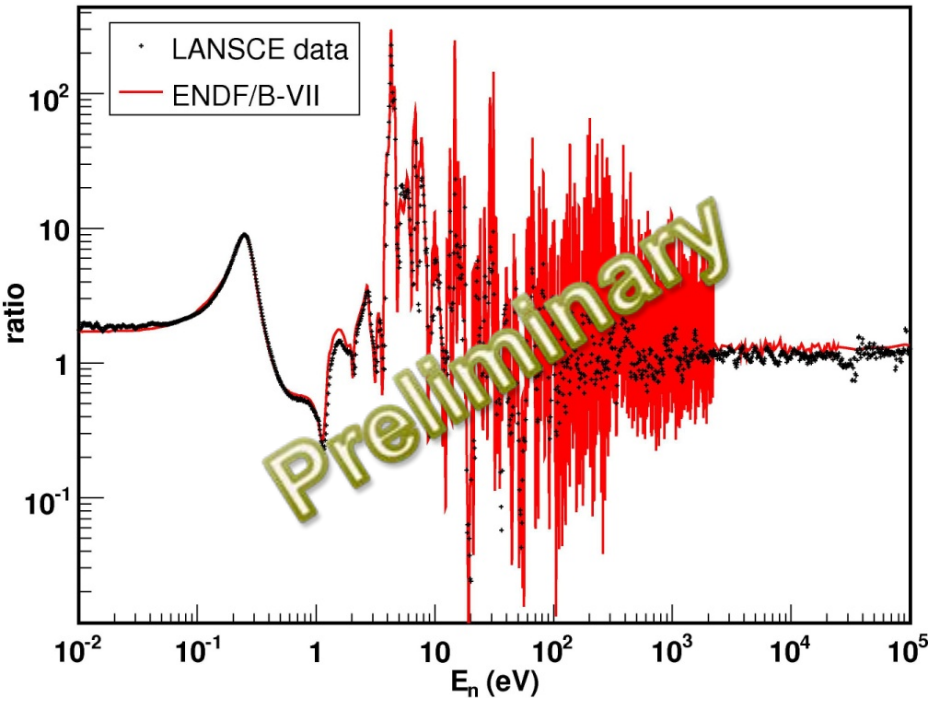
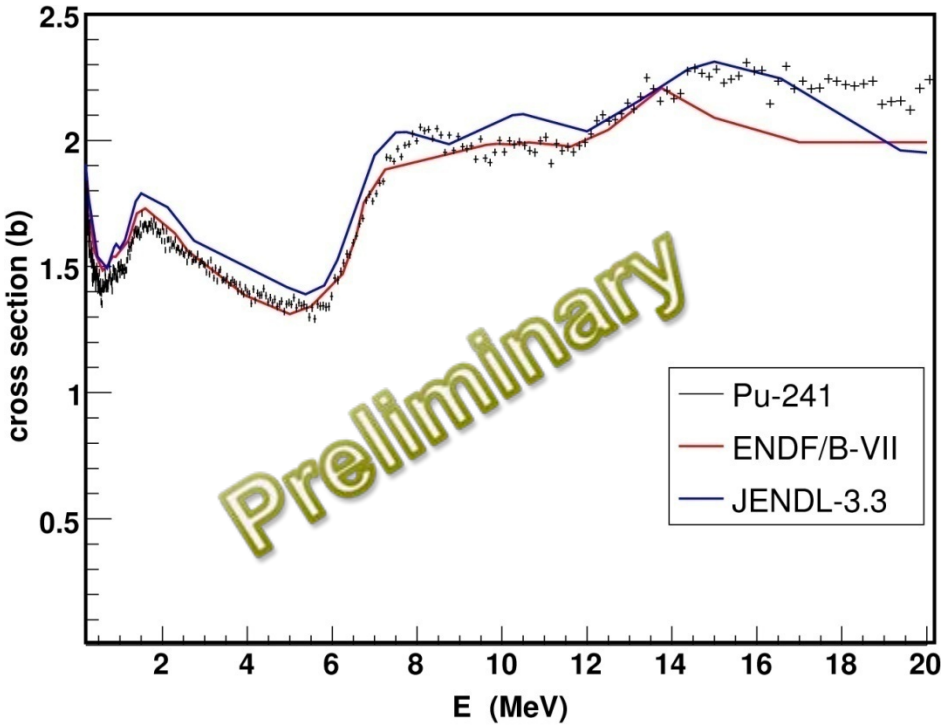
Measurements on Pu-241 σ(n,f)

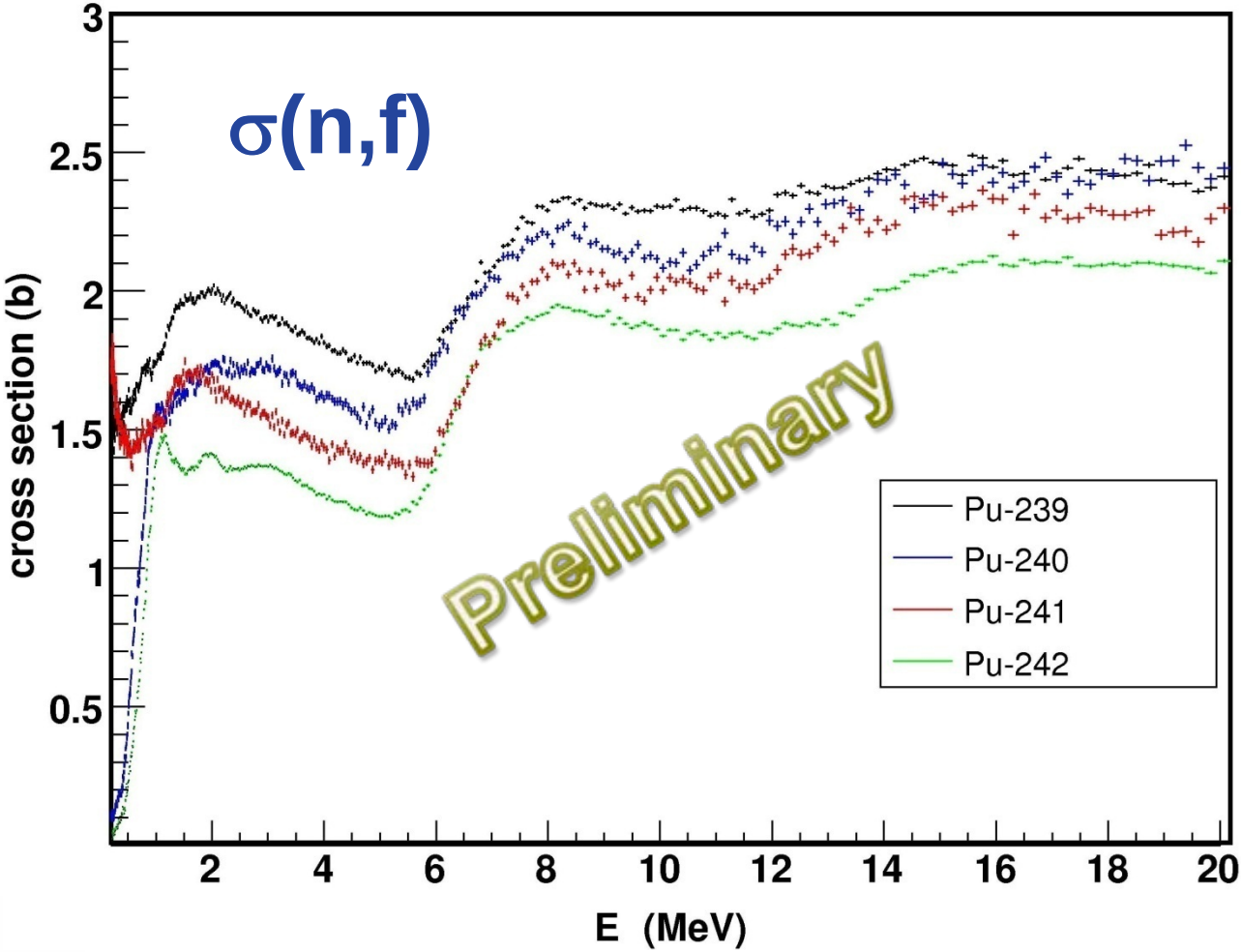




Preliminary results have been obtained over the full energy range

Additional measurements are being analyzed

Fission cross sections of $^{239\text{-}242}$Pu compared



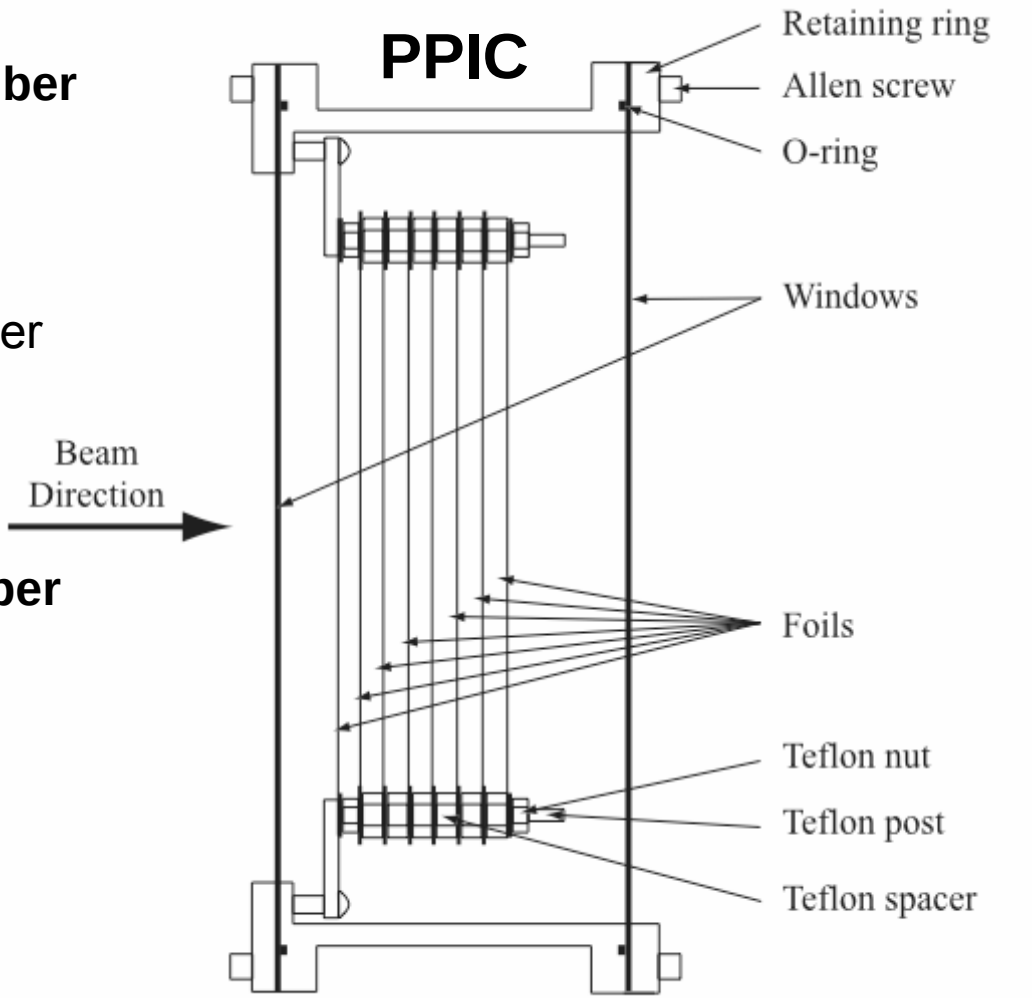
Parallel-plate fission ionization chamber is used for fission cross section measurements at present

Parallel plate ionization chamber (PPIC)

- Commonly used for flux monitoring
- Detects on fission fragment per even
- Holds up to 4 samples

Next – Time-projection chamber

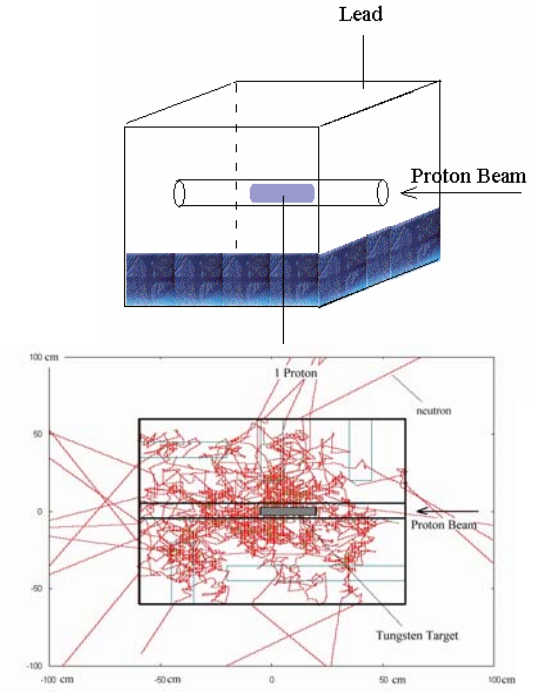
- Records
  - Angle Θ
  - Fragment energy $\mathbf{E_f}$
  - Track length → **Z,A**



Fission Cross Sections

On Very Small Samples

A Lead Slowing-Down Spectrometer is under development, driven by 800 MeV protons from the PSR

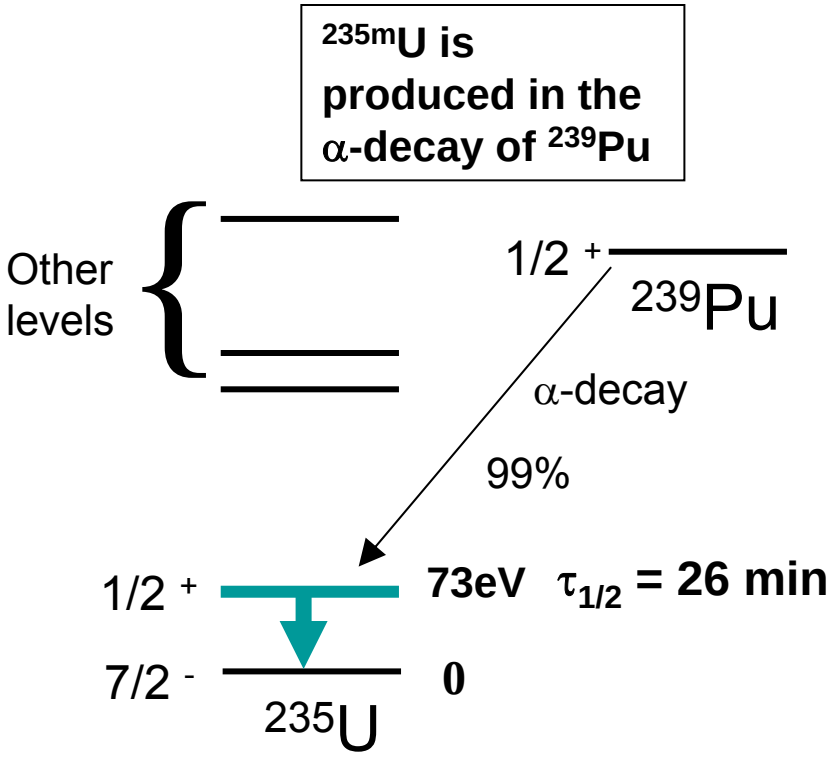


Neutron trajectories following the interaction of 1 proton with the tungsten target in the lead cube

Contact:
Bob Haight

First excited (isomeric) state of ^{235}U is produced in decay of ^{239}Pu

- **^{235m}U**
  - 26 min half-life
  - 73eV
  - Decays by internal conversion
  - 99% of 239Pu decays populate ^{235m}U
  - 5 gm of Pu produces 10ng of ^{235m}U
- Fast extraction of **^{235m}U** from **^{239}Pu** is required



We address the needs of LANSCE sponsors

- National Nuclear Security Administration
  - Program in radchem cross section measurements
    - Neutron capture cross sections on radioactive targets (DANCE)
    - Cross section measurements on high-order (n,2n), (n,xn) reactions (GEANIE)
  - Program in neutron-induced fission measurements
    - Fission product distributions (GEANIE)
    - Energy output in fission: neutron and γ-ray spectra (FIGARO)
    - Nuclear properties of fission products and isomers (GEANIE and FIGARO)
    - Cross sections on ultra-small samples (LSDS)
- Office of Nuclear Energy
  - Measurements in support of the GNEP program include:
    - Capture and fission cross section on actinides
    - Gas production: (n,p), (n,α) reactions in structural materials
- Office of Science
  - Support of SNS in studies of pulsed radiation effects on liquid mercury targets
  - Fundamental physics experiments and nuclear data
- National Resource
  - Nuclear science User Facility for defense, basic and applied research
  - Industrial testing of semiconductor devices in neutron beams
  - University research in nuclear science

The LANSCE program in nuclear data involves many laboratories

- GEANIE – LANL, LLNL , INL, ORNL, Bruyères-le-Châtel, NC State
- FIGARO – LANL, BNL, Bruyères-le-Châtel
- N,Z – LANL, Ohio U
- DANCE – LANL, LLNL, ORNL, INL, Colorado School of Mines, FZK Karlsruhe
- LSDS – LANL, LLNL, BNL, Bruyères-le-Châtel, RPI
- Fission – LANL, IRMM, LLNL, INL
- Others – MIT, Kentucky, Kyushu, Harvard,…